

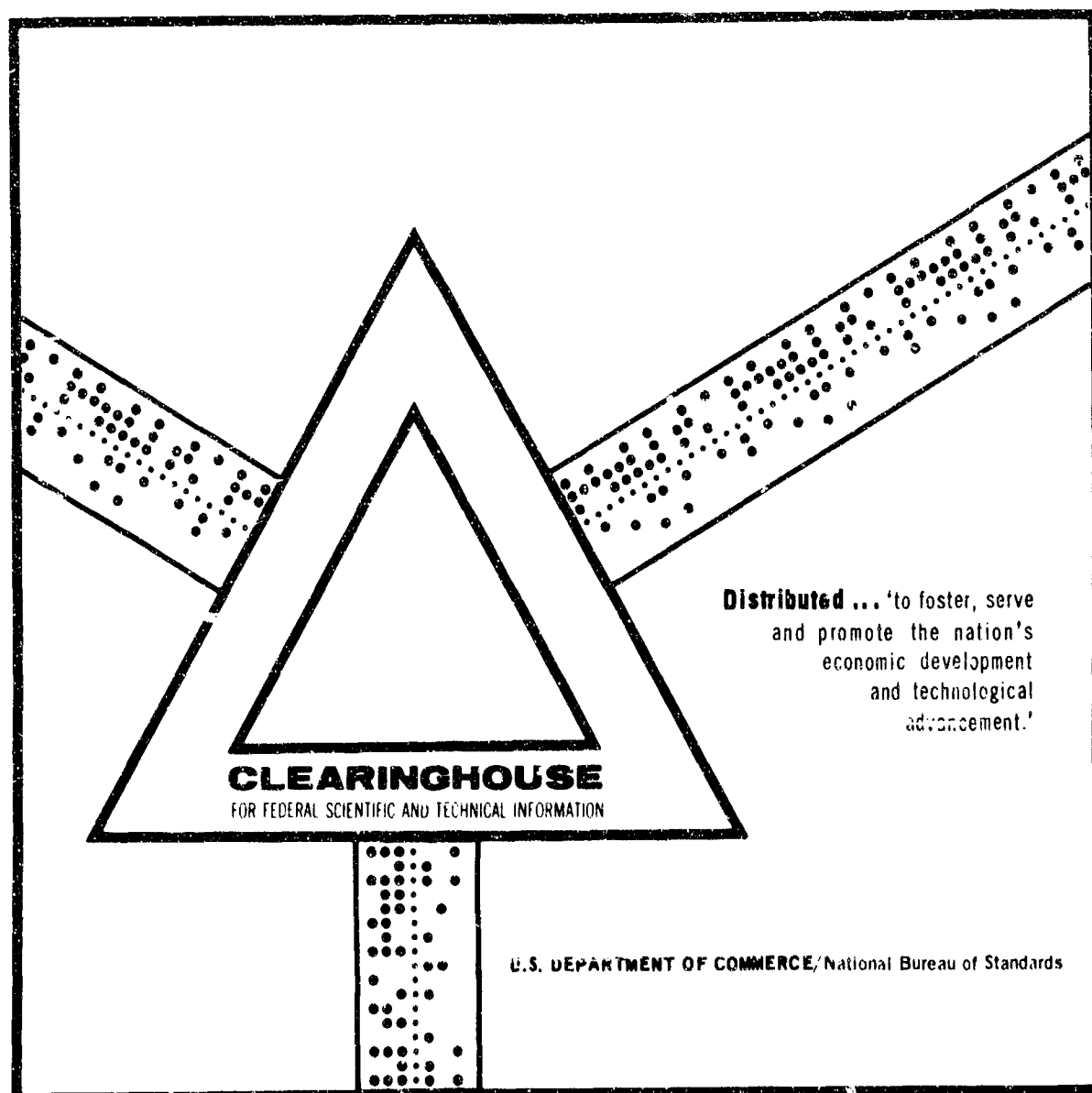
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OAR PROGRESS 1969

Jacob Seiden

Office of Aerospace Research
Arlington, Virginia

November 1969

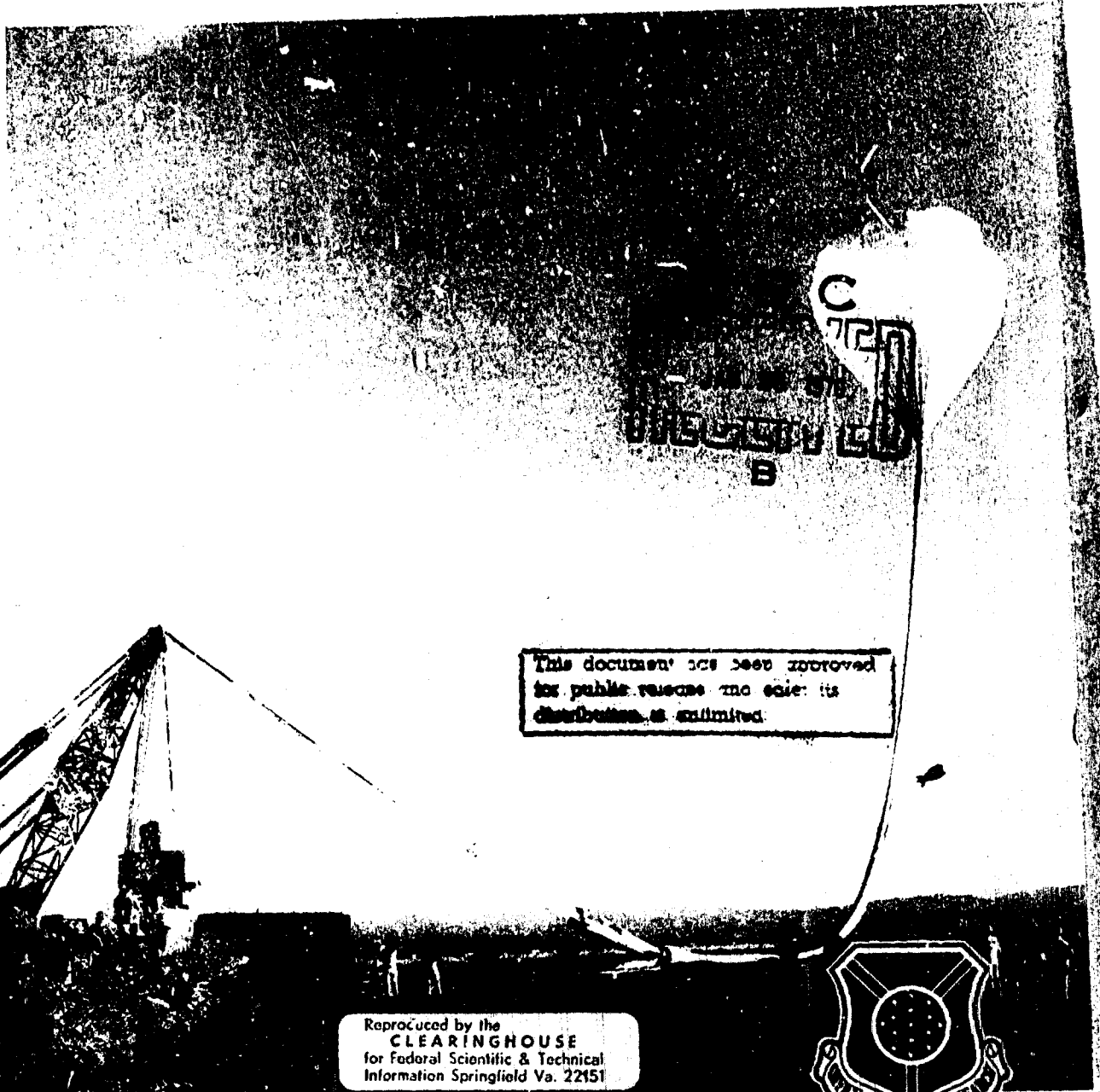


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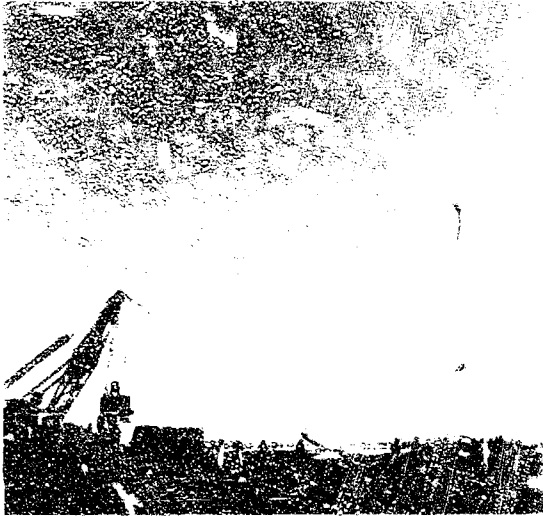
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OFFICE OF AEROSPACE RESEARCH ★ UNITED STATES AIR FORCE

162



Shown on the cover is one of AFRL's plastic balloons in a launch phase. AFRL, as the largest developer and user of balloons in the U.S., launches about 120 balloons each year. Many of these carry scientific payloads for AFRL. Most of them, however, are flown in support of research or development programs at universities, numerous DoD agencies, and other Government agencies. Not only does AFRL launch balloons, but it designs them as well. The primary goal is to increase the altitude/payload capabilities of these plastic balloons.

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OAR PROGRESS 1969

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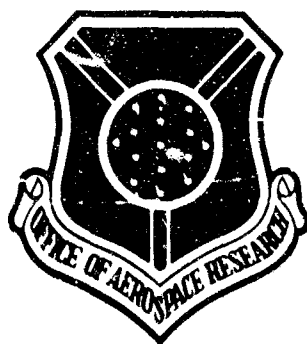
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Editor
Jacob Seiden



OFFICE OF AEROSPACE RESEARCH
United States Air Force
Arlington, Va. 22209

FOREWORD

The Office of Aerospace Research (OAR) has the responsibility for managing a broad research program relevant to the advancement of Air Force technology. This research is conducted at OAR's in-house laboratories, and sponsored at many university, technical-institute, and industrial laboratories throughout the United States and the free world. The new scientific knowledge resulting from this effort contributes to Air Force technological progress and increased capabilities.

OAR's research program is formulated in such a manner that is relevant to Air Force needs. Some of the highlights of progress made by the OAR research program are discussed in this publication.

It is the responsibility of the scientists and science managers of the Office of Aerospace Research to transfer the results of the scientific program to potential users as expeditiously as possible. This action, commonly called "coupling," is one of the most important aspects of the exchange of information throughout the technological communities.

It is our hope that this publication will make a meaningful contribution to this exchange of scientific information.



HARVEY W. EDDY
Brigadier General, USAF
Commander

CONTENTS

FOREWORD	iii
OAR COMPLEX	1
SCIENTIFIC ADVISORY GROUP	4
FINANCIAL RESOURCES	5
HUMAN RESOURCES	9
LOGISTICS	14
FUTURE OUTLOOK	16
RESEARCH INFORMATION ACTIVITIES	17
SCIENTIFIC PROGRESS, FY 1969	21
Defense Research Sciences P.E. 61102F	23
General Physics	23
Nuclear Physics	46
Chemistry	48
Mathematical Sciences	60
Electronics	68
Materials Research	74
Mechanics	79
Energy Conversion	91
Terrestrial Sciences	97
Atmospheric Sciences	98
Astronomy and Astrophysics	104
Biological and Medical Sciences	106
Behavioral and Social Sciences	108
Environment P.E. 62101F	111
Aerospace Avionics P.E. 62403F	131
Ground Electronics P.E. 62702F	132
Satellites, Balloons, and Sounding Rockets-SABAR P.E. 63404F	137
BIBLIOGRAPHY	139

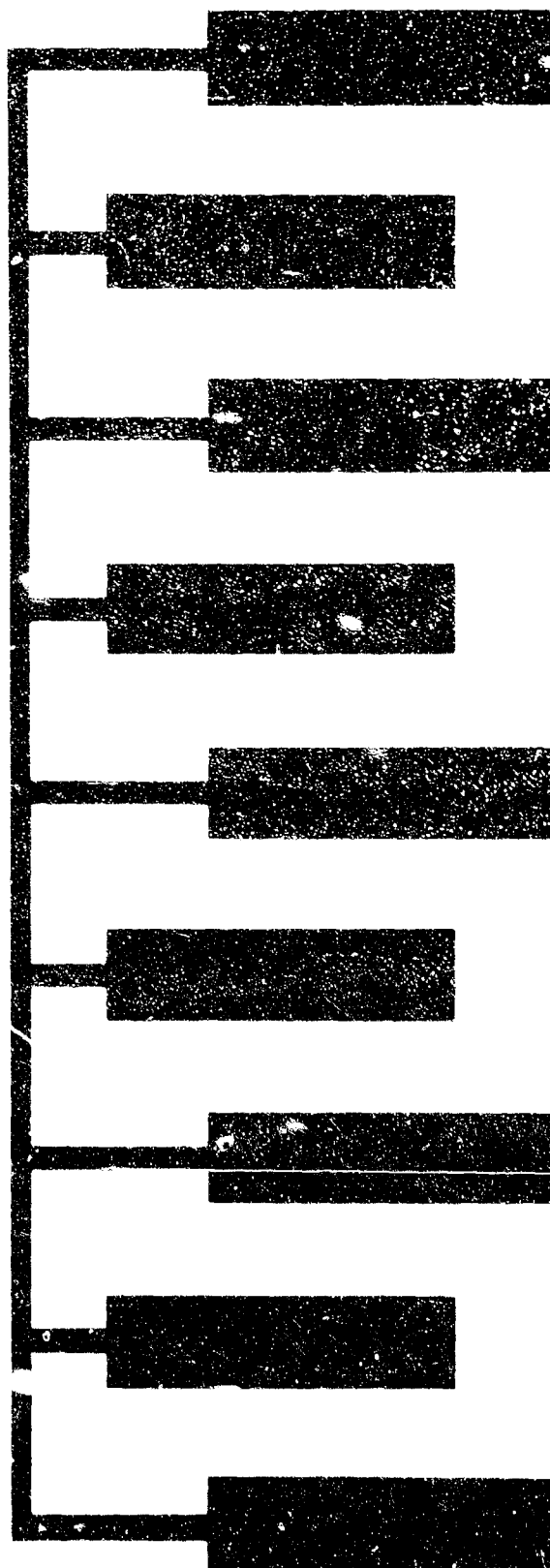
OAR COMPLEX

The Office of Aerospace Research is composed of the Headquarters and 9 subordinate units, 5 of which are major research organizations, 2 predominantly research-supporting units, and 2 field liaison offices. The major research organizations are the Air Force Cambridge Research Laboratories (AFCLR), the Air Force Office of Scientific Research (AFOSR), the Aerospace Research Laboratories (ARL), the Frank J. Seiler Research Laboratory (FJSRL), and the Office of Research Analyses (ORA). The research-supporting units are the European Office of Aerospace Research (EOAR), and the Latin American Office of Aerospace Research (LAOAR). The field liaison offices are the Patrick Field Office (PFOAR) and the Los Angeles Field Office (LOOAR). Of these 9 units, 7 are in the continental United States, and the remaining 2 are in Belgium and Brazil.



**HQ OFFICE OF
AEROSPACE RESEARCH
Arlington, Va.**

Manages the conduct and support of research in those areas which offer the greatest potential for providing new knowledge essential to the continued superiority of the Air Force operational capability. Also manages the conduct and support of specifically assigned exploratory-development efforts.



AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. Hanscom Field, Bedford, Mass.

Does research in the physical, engineering and environmental sciences, and conducts specifically assigned exploratory-development efforts involving the physical, engineering, and environmental sciences. Contracts for research and development work which closely supports and extends in-house efforts.

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Arlington, Va.

Through contracts and grants, supports programs of extramural research designed to provide new scientific knowledge and understanding. Areas of research include the physical, engineering, environmental and life sciences.

AEROSPACE RESEARCH LABORATORIES
Wright-Patterson AFB, Ohio

Conducts research in the physical and engineering sciences, and contracts for research which closely supports and extends in-house efforts.

THE FRANK J. SEILER RESEARCH LABORATORY
USAF Academy, Colo.

Conducts research in chemistry, applied mathematics, and aerospace mechanics. Fosters, encourages, and supports related research by the USAF Academy faculty and cadets.

OFFICE OF RESEARCH ANALYSES
Holloman Air Force Base, N. Mex.

Conducts mission analyses to identify future aerospace missions; conducts systems analyses to determine technical validity, operational feasibility, and cost-effectiveness of future Air Force systems; and conducts research analyses to identify promising research opportunities, applications, and methodologies.

EUROPEAN OFFICE OF AEROSPACE RESEARCH
Brussels, Belgium

Secures in Free Europe, the Near East, Middle East (including India, Burma, and Ceylon), and Africa, scientific research and development efforts in support of the programs of Air Force organizations, and provides scientific liaison which fosters mutually beneficial relations with the scientific communities of those areas.

LATIN AMERICAN OFFICE OF AEROSPACE RESEARCH
Rio de Janeiro, Brazil

Administers research efforts in South America.

PATRICK FIELD OFFICE
Patrick Air Force Base, Fla.

LOS ANGELES FIELD OFFICE
Los Angeles, Calif.

These field offices support the aerospace research effort of the Air Force through the installation of scientific experiments fabricated by Air Force laboratories in rockets and satellites, and arrange for data collection. They also maintain liaison among the Air Force scientists, the launch teams, and the contractors.

SCIENTIFIC ADVISORY GROUP

The OAR Scientific Advisory Group is a key element in helping OAR to develop and maintain an effective research program for the Air Force. The Group, associated with OAR in its planning activities, advises the Commander as to the nation's capability in science, and identifies trends and emerging potentials in areas of science that could afford the Air Force an improved capability. The Scientific Advisory Group reviews the OAR research program on a continuing basis.

During FY 69, the Scientific Advisory Group met at the Aerospace Research Laboratories (Dec 1968) and at the Laboratory of Gulf General Atomic, Incorporated at San Diego (May 1969). Both meetings consisted of briefings or discussions of items of interest to the OAR staff. The December meeting was Dr. J. Laurence Kulp's first conference with the entire Group since becoming a member in August

1968.

Members of the Group also serve on Boards of Visitors (BOV) to the OAR laboratories and to AFOSR. In this capacity, they help the OAR Commander to evaluate the effectiveness of each organization in making scientific contributions of importance to the Air Force. Further, they recommend measures to enhance this effectiveness. The members also act as advisers to each of the OAR laboratories and to AFOSR.

Boards of Visitors' meetings were held at each Laboratory and at AFOSR in the fall of 1968. The dates were as follows: ARL BOV, 4-5 Oct. 68; AFCRL BOV, 4-5 Oct. 68; FJSL BOV, 15 Nov. 68; and the AFOSR BOV, 22-23 Nov. 68. Unit Commanders discussed their programs and individual philosophies of operation with the BOV members.

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*Dr. Joseph Kaplan was Chairman of SAG through FY 69. Dr. Langmuir became Chairman beginning with FY 70.

FINANCIAL RESOURCES

Funding received by the Office of Aerospace Research during Fiscal Year 1969 is summarized by program element in the following table:

<u>Program Element</u>	<u>Funding in Millions</u>
In-House Laboratory Independent Research	1.1
Defense Research Sciences	90.8*
Environment	10.2
Aerospace Research Support (ARSP)	5.0
Balloon Components and Techniques	.5
Command Management and Base Operations	3.2
RAND	12.5
ANSER	1.2
TOTAL	124.5

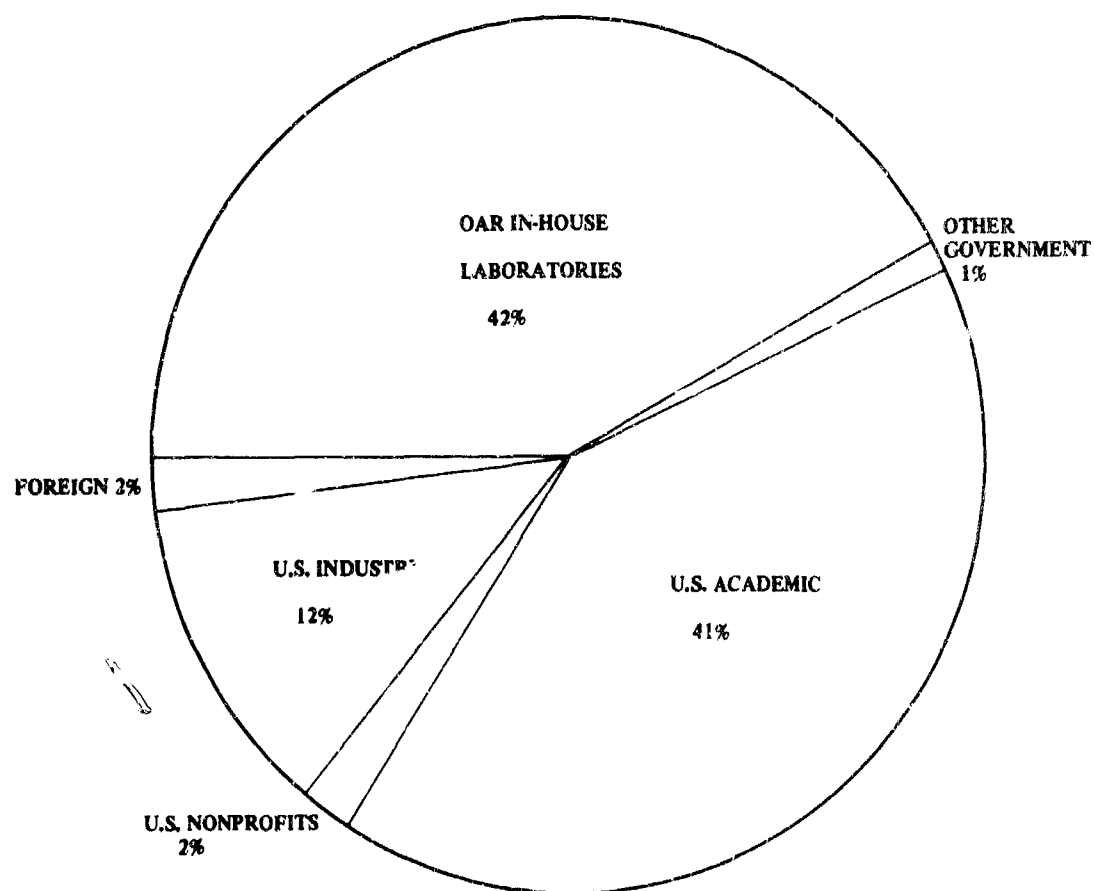
*Includes \$2,484,000 of Project THEMIS funds.

The Defense Research Sciences (DRS) and the In-House Laboratory Independent Research program elements constitute the complete basic-research program for the United States Air Force, whereas the Environment program element covers exploratory-development efforts in environment only. Aerospace Research Support funds provide the hardware and payload build-up for aerospace satellite experiments. The In-House Laboratory Independent Research funds provide a source of dollars, largely unrestricted in application, with which an individual laboratory director can initiate new work in his organization's area of interest. The Balloon Components and Techniques funds are used to develop new and improved balloon capabilities to meet USAF needs in a wide variety of atmospheric and extra-atmospheric research programs. Command Management and Base Operations funds cover the operating expenses of the Headquarters and the field offices.

For Fiscal Year 1969, the OAR basic-research (DRS) funds were distributed by fields of science, or subelements, as shown below:

<u>Defense Research Sciences Subelement</u>	<u>Funding in Millions</u>	<u>% of Total DRS Funds</u>
General Physics	16.1	17.7
Nuclear Physics	2.5	2.8
Chemistry	5.0	5.5
Mathematical Sciences	5.8	6.4
Electronics	8.8	9.7
Materials Research	2.5	2.7
Mechanics	7.6	8.4
Energy Conversion	7.0	7.7
Terrestrial Sciences	1.4	1.5
Atmospheric Sciences	14.6	16.1
Astronomy and Astrophysics	6.4	7.1
Biological and Medical Sciences	2.1	2.3
Behavioral and Social Sciences	2.5	2.8
Project THEMIS	8.5	9.3
TOTAL	90.8	

The DRS program element supports the operating costs of the Air Force Cambridge Research Laboratories, the Air Force Office of Scientific Research, the Aerospace Research Laboratories, and the Frank J. Seiler Research Laboratory, as well as the grant and contractual research monitored by these organizations. The breakout of the FY 1969 DRS program (exclusive of Project THEMIS) by performer type is shown in the following pie chart:



FOREIGN RESEARCH, ITS IMPORTANCE AND MANAGEMENT

Historically, during the last quarter of a century, many technological contributions from foreign scientists have been of direct value to the Air Force. For the most part, during this time, new ideas leading to basic theoretical progress, particularly in the atomic sciences, were sparked by foreign scientists, primarily European, or by scientists trained abroad.

For over 17 years now, the Air Force has been engaged in cooperative research with European nations and with other countries of the free world. We have developed a mutual working base aimed at technological advancement. Speaking strictly in terms of scientific research, OAR's contracts and grants for foreign research represent a means for utilizing foreign brainpower to meet the needs of the Air Force.

In order to facilitate the flow of scientific information from the foreign scientific community to the Air Force scientists, and to foster and strengthen their intercommunication, OAR has maintained two offices abroad, one at Brussels, Belgium, and the other at Rio de Janeiro, Brazil. At Brussels, the European Office of Aerospace Research (EOAR) has managed the Air Force's foreign-research activities in Free Europe, the Near East, the Middle East (including India, Burma and Ceylon), and Africa. At Rio de Janeiro, the Latin American Office of Aerospace Research (LAOAR) has managed the Air Force's foreign-research activities in South America. On the other hand, the Air Force's foreign-research activities in Canada, Australia and New Zealand are administered directly from Air Force agencies in the U. S. In the Far East (Japan, Taiwan, and South Korea), procurement of foreign research for the Air Force is handled by the Army's research office in that area.

In securing foreign-research efforts in support of the Air Force programs, EOAR acts as an on-the-spot broker for the stateside Air Force research laboratories. Its procurement and technical staffs negotiate the terms of the contracts or grants that serve as the instruments to accomplish the work desired. Although the stateside organizations pay for this research, EOAR is responsible for coordinating the activities between these stateside sponsoring agencies and the foreign scientist contractors or grantees.

The various foreign-research activities in EOAR's area of responsibility have been financed primarily through funded contracts, all of which have been "cost-shared" by the stateside organizations and the European institutions. During the past year, however, because of severe budget and "gold-flow" restrictions, support for some of OAR's contractors has had to be

discontinued. Thus, EOAR has been faced with the perplexing problem of having to continue this retrenchment of Air Force dollar expenditures for research contracts and grants abroad while at the same time trying to maintain our ties with leading foreign scientists, and possibly even attract new ones in support of the Air Force research program.

For some time, now, OAR has been cutting back on the cost of foreign research borne by the Air Force so as to contribute to stemming the "gold flow" and thus counteracting its adverse effect upon the Nation's balance of payments. Towards this end, OAR financed research in both FY 1968 and FY 1969 with about \$500,000 in U.S.-owned excess foreign currencies, and with about \$2.0 million realized from U.S. surplus barter commodities sold abroad. Also, OAR encouraged the increased purchase of U.S.-manufactured scientific equipment and supplies by foreign grantees and contractors, and an increase in cost-sharing by the scientist's institution. In fact, during FY 1969 the host institutions provided an average of 60% of the total cost of the research. This has led to increasing success in our efforts to minimize the balance-of-payments impact, while at the same time maintaining strong ties with the foreign scientists.

Recently, OAR has sought to utilize a new approach for acquiring the benefits of foreign research for the Air Force. This would envisage the establishment of a working relationship between Air Force scientists and their counterpart foreign scientists through a so-called "one-dollar" contract. Such a "one-dollar" contract would reflect the mutual research interests of the American and foreign scientists, and provide a mechanism for direct scientific contact and dialogue. Under this no-cost contract, a foreign scientist would become a member of a research team, and would have an opportunity to attend contractors' meetings in the U.S., and also have access to the contractors' facilities. In return, he would supply OAR with current technical reports and periodic personal briefings on his research, thus cooperating in a direct interchange of scientific information.

There are indications that a number of outstanding European scientists may be interested in this "one-dollar" contract arrangement. Such an arrangement could become a significant supplement to foreign research funded by the Air Force, and could provide an additional avenue for the Air Force to benefit from the expertise of the foreign scientific community.

THE OAR MANAGEMENT AND SCIENTIFIC INFORMATION SYSTEM (MASIS)

Several thousand scientists at several hundred Government, academic and industrial laboratories do basic research for OAR. This research encompasses every scientific discipline which is relevant or potentially relevant to the continued superiority of the Air Force operational capability. It is the mission of OAR to manage this large and diverse research program, not only to assure that the research dollar is spent wisely, but also to disseminate the results of this research to the Government and scientific communities.

The OAR Management and Scientific Information System (MASIS) is a computer-based data system which accumulates data on the many research efforts comprising the OAR Research Program. MASIS data is organized into four master files which correspond to the stages associated with the selection and performance of research: the "Proposal," "Fiscal," "Narrative," and "Publication" Files.

The Proposal File stores the unsolicited proposals for research received by OAR, and maintains a record on the status of each proposal. The Fiscal File records the funding associated with accepted proposals, as well as other information, including the title, performer, the performing organization, and its location. The Narrative File describes, in abstract form, the purpose, approach, and relevance of the research, as well as the progress of on-going work. The Publication File lists all published documents resulting from the individual research efforts. Thus, the questions of who, what, when, where, how, how much, and why, relative to OAR, can be answered by the data stored in these master files.

MASIS is thus a centralized repository of information obtained from many sources which document the OAR Research Program. Its purpose is twofold: to assist in the day-to-day management of this program within OAR; and to serve as a source of information in response to questions or requirements posed by higher authorities. In the latter category, MASIS is used continually to answer questions from the Congress, Department of Defense, and Hq USAF concerning the OAR Research Program.

An information system such as MASIS must be responsive to the continually changing needs of management. This required flexibility is complicated by the fact that MASIS serves various OAR activities which have different management needs and pursue different practices. Thus, MASIS must be so structured as to permit specific changes in its system design to meet new requirements unique to a particular OAR activity, while at the same time retaining

those capabilities which have been found by experience to be useful and important to all activities.

The information contained in MASIS can be combined in many different ways so as to produce a wide variety of specialized reports. The illustration (Figure 1) shows a printout which displays all information in the files describing a particular research effort. Each of the data elements included in the illustration can be extracted and, in conjunction with the same and different elements in other records, can be used to generate various summary reports, for example—the number and names of scientists conducting research for OAR, the fund allocations to particular projects, research titles by key words, and many others.

Useful information is sometimes a far cry from mere data; thus, OAR seeks constantly to improve MASIS. For this purpose a MASIS Design Group, consisting of representatives of all OAR activities concerned, meets quarterly to review the operation of the system and to suggest improvements. Consequently, MASIS is not only an operational system, but also one which is continually absorbing improvements in design which will permit it to provide better service to OAR management.



Figure 1.



HUMAN RESOURCES

PEOPLE

Our Most Important Resource

For its success as a research organization, OAR depends on its people—on their creativity, their imagination, their professional ability, and their diverse motivations and approaches. To obtain research of quality, OAR must attract and hold first-rate people. It offers them a stimulating working environment in which there is ample room for individuality.

OAR is composed of some 300 officers, 200 airmen, and 1,500 civilians. Of the 300 officers assigned, approximately 250 are in the scientific and engineering career fields. Because of the emphasis placed on advanced education in the scientific fields, the officers assigned to the Command have, as a group, one of the highest educational levels in the Air Force. Sixteen percent of our officers possess PhDs; 65 percent have master's degrees; and 18 percent have bachelor's degrees. Of the 1,500 civilians, some 770 are employed in the scientific area; 30 percent have doctoral degrees, 31 percent possess master's degrees, and 32 percent possess bachelor's degrees.

The average civilian grade in OAR is the highest in the Air Force—a grade of GS-10. The majority of our professional civilian personnel are in grades GS-13 and above. Also, there are 25 PL313s and 31 GS-16s assigned within OAR. These represent special authorizations granted by the Civil Service Commission in order to attract eminent scientists from private industry and thus utilize their professional scientific and engineering capabilities.

MILITARY PERSONNEL

"Selective Manning"

In order to insure that OAR obtains only the best-qualified officers and airmen to support and fulfill its basic-research mission, the Command goes to great lengths to achieve compatibility between a

particular position, and the education and background of the individual selected to fill that position. A phrase has been coined which covers this unique military-personnel management policy. It is called the "selective manning system."

When there is a position vacancy in one of the units, OAR forwards a requisition to the HQ USAF Military Personnel Center (MPC), outlining the specific requirements for the particular position. MPC then forwards selection folders to OAR which, in turn, forwards them to the unit where the vacancy exists. If the unit believes the individual possesses the necessary qualifications to perform the job, notification of his acceptability is relayed to MPC. However, if the unit does not believe the nominee to be capable of meeting OAR's high-performance standards, his folder is returned to MPC, and additional nominees are requested.

"Project PhD"

OAR is currently authorized 91 military PhDs, but has only 51 assigned. A special project entitled "Project PhD" has therefore been established in an effort to improve this manning level. It identifies each PhD position authorized within the Command, details what the specific requirements of the position are, and identifies the officer currently filling the position. After identifying OAR's valid PhD requirements, "Project PhD" seeks to fill these high-level positions with officers possessing PhDs in order to satisfy the requirements of these positions. Thus, OAR will not assign an officer to one of these positions unless there is a strong probability that he will be able to obtain his PhD during the first year of his assignment.

"Career Development"

OAR places a great deal of emphasis on the career development of its officers, particularly those young officers who come "on board" with advanced degrees. The experience of our Command has been that proper career progression must be provided in order to motivate these officers to remain with the Air Force. Recently, OAR initiated the OAR Commanders' Education Program which allows the Command to select a small number of outstanding officers each year for entry into the AFIT Master's and PhD Programs so as to meet future manning requirements in specific academic disciplines. Upon completion of their AFIT programs, these highly trained officers are returned to OAR and assigned to key research and middle-management positions in order to utilize their skills and knowledgeability. This long-range career progression allows OAR to develop a nucleus of talented scientific officers especially capable of man-

aging OAR's basic-research activities. It also establishes a strong career-development pattern for these promising young officers.

Although many of OAR's officers already possess advanced degrees, the Command encourages its officers to apply for AFIT programs in competition with officers from other commands. And, in order to meet the very critical specialties required to pursue basic research, OAR has authorized Command short-course training for both officers and airmen whose duties require up-to-the-minute expertise in the latest scientific research techniques. Each military supervisor is encouraged to initiate requests to enroll officers and airmen in both on- and off-duty courses at local colleges and universities so as to increase their job proficiency. Under OAR's Command Short-Course-Training Program, the Air Force pays for all of the tuition and books for the various courses, and also makes available per-diem funds for travel, if necessary.

"Career Broadening"

Approximately 83% of our officers work in highly specialized areas in research and development. For this reason, OAR is concerned that its officers experience career broadening, which is considered vital to their continuing growth as professional Air Force officers. As a result, the assignment to OAR for both officers and airmen is limited to a four-year tour, after which they are considered for assignment to other major commands. A recent study clearly indicated that the large majority of OAR's officers are being reassigned to operational commands. This continuing cross-fertilization of our scientific and engineering officers throughout the operational commands of the Air Force has resulted in the growth of a large corps of highly skilled S&E officers with considerable operational knowledge. The future of our Nation may well rest someday with these talented officers who seek daily to keep the United States Air Force "ahead of the competition" in international technological developments.

"Career Motivation"

Although assignment to OAR is a highly desirable one, OAR, like the rest of the Air Force, has its problems with retention, particularly of the young officers with advanced degrees in the S&E areas. Although OAR is proud of the fact that its officer retention rate has steadily increased over the past nine years, it seeks to make an Air Force career even more attractive to these people in order to retain more of them in the Air Force. During the 1963-1966 time period, the primary reason given by OAR's young officers for leaving the Air Force was "low

pay" and "lack of promotion opportunity." However, recent Command surveys now show that the prime reason given by these officers is "no desire for a military career." While it is a relatively easy task to identify, and recommend solutions to, the "low-pay" and "poor-promotion-system" complaints, it is a far more difficult task to improve the image of the Air Force for these young officers. Many of them have recently come directly from college campuses where it is "in vogue" to express disenchantment with the "military establishment." Thus, we have a four-year period in which to create a positive image of the Air Force's way of life, and to so motivate these officers that they will choose to remain with us for a full military career. This is a very critical task, since we depend upon a continuing influx of these young scientists and engineers to provide the future technical leadership of the Air Force. It is obvious, then, that we must continue to place a great deal of emphasis on the career motivation of our young officers.

CIVILIAN PERSONNEL

Its research mission, and the aspirations and composition of its civilian workforce, distinguish OAR from the typical Air Force organization. OAR strives to preserve each person's individuality in order to promote creativity and to provide the freedom and flexibility essential to the continued growth of science and technology. Consequently, standard personnel management procedures are of limited use in this Command, and OAR must make special adaptations of standard civilian-personnel programs and procedures.

For example, OAR's laboratories are given a great deal of flexibility in the utilization of their personnel resources. They are permitted to transfer civilian-personnel resources from one area to another in order to meet the increasing research needs of the Air Force. In all of these actions, however, the career development of the individual is considered, since proper career management is vital if OAR is to continue to motivate these highly educated personnel.

Wherever possible, we follow a "promote-from-within" policy in our civilian-personnel administration. Approximately 60% of our newly employed civilians are hired at the GS-11, GS-12, or GS-13 position level. After they have performed satisfactorily for a number of years, we consider them for advancement to the higher grades to fill existing vacancies.

Since the need in basic research is for individuals with a great deal of background and experience in their disciplines, we do not hire newly graduated scientists and engineers at the GS-5 or GS-7 level for

training in their specialties. However, because of the attractiveness of working in a research environment, we have been able to employ the more experienced personnel we need, and have not had to recruit civilian employees from undergraduate and graduate schools.

If there is one critical element which must be considered in each civilian-personnel action taken in the Office of Aerospace Research, it is the law of supply and demand. Since the great bulk of the OAR civilian-personnel workforce consists of professional scientists and engineers, we compete constantly with private industry and other Government agencies for the best qualified people. However OAR, unlike most other organizations, may actually recruit a nationally known scientist to perform research in one of its in-house laboratories, and then secure a position to which to assign him. Most of the initial contacts with these key individuals are made by our scientists at various symposiums, at universities, and at professional meetings. In all civilian-employment actions, the local host-base Civilian Personnel Office provides the necessary arrangements for the actual hiring.

Many prominent professors at leading colleges and universities doing basic research in key areas are encouraged to take a sabbatical from their university functions for duty with the Government. We encourage these professors performing research of interest to the Air Force to "come on board" for one-year appointments to work on, or assist in the completion of, a specific basic research project. At the conclusion of the one-year appointment, these individuals return to their college campuses.

OAR also has the authority to hire nationally famous scientists and engineers for up to four-year periods in order to complete specific scientific projects. This type of employment is for the individual who is interested in completing a special research project in his academic discipline but who is not interested in a career Civil Service position.

"Employee Development"

OAR makes full use of the Government Employees Training Act to increase the on-the-job proficiency of its personnel, and to upgrade their academic levels. Historically, OAR has been manned with people who have a very positive attitude toward all types of training. They realize that continuous training is necessary to enable them to widen the areas of research. The professional scientist or engineer, dedicated as he is to his work, fully realizes that the more knowledge he accrues, the more he is capable of achieving, and thus the greater his chances of advancement will be. There are basically two types of training authorized within OAR: Government and non-Government. Because most of our training needs

can best be met by civilian universities and colleges, this Command sends the majority of its employees to non-Governmental institutions.

Under the long-term, full-time training program, selected personnel are allowed to participate in professional training for a minimum of one year, and a maximum of two years. These personnel are enrolled in academic courses leading to the award of an MS or PhD in their particular specialties. In addition, some of our personnel presently possessing PhD's are sent to a university or college in a "visiting-scholar status," rather than as a student. These visiting scholars are provided with office space and general administrative support by the school which has extended the invitation. There are no tuition costs for the scholar, who can audit any high-level graduate course. In return, he performs research on projects currently being undertaken by the university. This program benefits both the university and the Air Force in that it affords the visiting scholar an academic atmosphere conducive to learning more about his specialty, while at the same time providing the Air Force with essential contacts with the academic community.

OAR's short-term, full-time training program is similar to the long-term training program except for its maximum training-time period of six months. This program provides our civilian personnel with specific training to bring them up-to-date in the latest research techniques in their professional areas.

Our employees are encouraged to take off-duty courses. The Government pays the complete costs of tuition and books, and the individual attends in the evening hours. Off-duty courses are designed primarily for those professionals desiring to upgrade their academic levels.

There are also short-term courses of one-to-four weeks' duration. These are usually conducted by colleges and universities or professional organizations, and cover specific aspects or techniques associated with a specific discipline. For example, an OAR civilian laboratory director may attend a two-weeks' American Management Association course entitled "Management of Research" in order to improve his management expertise.

In the above-mentioned courses, where there are tuition fees, or costs for books or per diem, these costs are paid completely by OAR. However, OAR also encourages its civilian employees to take off-duty educational courses in those areas in which they have a personal interest not necessarily related to their jobs. Although the employees pay the complete costs of these courses, OAR does encourage the unit commanders to adjust working hours, if necessary, so that the employees may have the opportunity to attend these courses. Here again, OAR does everything possible to enhance the morale and motivation

of its people since, in the long run, this is what stimulates greater creative performance—a real necessity in the world of basic research.

"Impact-of-the-Man-on-the-Job Program"

Another civilian-compensation program maintained by OAR is the Impact-of-the-Man-on-the-Job Program, designed especially to encourage our technical professionals to be creative and productive.

For many years, the high-level managers of OAR have sought to assure that key civilian scientists and engineers receive proper compensation as their educational and experience levels rise. Each supervisor of professional scientists and engineers in each of our organizations annually reviews the position level and duties of each professional employee so as to insure that the level of duties being performed by each such individual is reflected in his grade. In many instances we have scientists whose stature in their profession grows as the result of their professional achievements. This professional growth is normally reflected in a higher level of performance. Thus, in those instances where an individual's performance and professional stature exceed his current grade level, immediate action is taken to try to upgrade those positions.

"Recognition and Awards"

Our professional scientists and engineers are intensely work-oriented, and eager to utilize their talents to discover new knowledge in their basic-research areas. Much of their professional standing is tied up in the work they are doing. If they are involved in basic-research projects that are challenging and contributory to existing knowledge, then they can prepare scientific papers on their work with resultant professional recognition by their colleagues. This is perhaps the recognition they prize most.

However, there are a number of significant awards both within the Government and in private industry which some of our key scientists have received, and which point up the excellence of their performance. Among these are the following: the Air Force Decoration for Exceptional Civilian Service, the Goddard Awards, the Federal Woman's Award, and the DOD Distinguished Civilian Service Award.

In addition to the above, we continue to utilize the provisions of the joint Military Civilian Recognition Program in order to reward our employees for scientific achievements, or contributions to efficiency, economy, or other improvements in Governmental operations which are above those normally expected. This program authorizes cash awards which can range from \$25 to \$25,000. During the past year, one of our high-level scientists received a cash award of \$5,000 for a very significant contribution in the

field of radio astronomy. Although an award of this amount is an exception rather than the rule, it does reflect the opportunities available to our technical personnel to receive substantial bonuses for their efforts beyond those normally given. Most of the landmarks in basic research have been established by individuals; this must necessarily be so since the creative process is a very personal thing. Thus, we stress recognition of the individual in our civilian-awards program, for it is the individual who is the key to the success of our basic-research program.

"The Personnel Outlook"

As we look to the future personnel requirements

of OAR, we see a definite requirement for the development of technically competent military officers who will have the leadership qualities necessary to manage the basic-research programs of the 1970s. We envision, also, the tremendous task of recruiting and developing young civilian scientists who will initiate the vital programs necessary to insure that the U.S. Air Force of the future will attain the technological superiority necessary to stay ahead of the competition. Although we believe that our current positive personnel-management program can accomplish these tasks, we intend to continually explore new procedures and practices so as to insure that the finest basic-research scientists in the world become employees of the Office of Aerospace Research.



LOGISTICS

Logistics

OAR's new Laboratory Supply Support Procedures continue to be an effective management tool. Each level of management has become a vital link between basic-research personnel and the normal sources of supply. Since its inception in 1967, a general trend of improvement has been recognized to the extent that other Air Force research agencies have proposed implementation of these procedures within their own organizations. A remarkable increase in Internal/External Excessing Actions has been noticed. During the past 2 1/2 years, a total of 2,358 items of equipment valued at \$7,212,000 were returned to the Air Force Supply System. Equipment Utilization Surveys, Special Temporary Storage Areas, dollar-value controls, and the appointment of Laboratory Directors/Chiefs as members of Equipment Review and Authorization Activities have all contributed extensively to the improved operation of this new system. The system will continue to be a part of the overall laboratory operations manned from existing laboratory-personnel resources. It has been incorporated into the overall Air Force supply procedures applicable to selected RDT&E organizations.

Procurement

OAR has continued to promote a dynamic, responsive procurement system in support of its scientists and laboratories. Deviations and exemptions from standard procurement policies have been obtained where such policies have failed to recognize the unconventional nature of research. Reporting requirements have been reviewed to insure that unnecessary effort is not expended in this area. This review has resulted in cancellation of reporting requirements that had been established by Hq USAF and Hq OAR.

The Commodity Credit Corporation (Department of Agriculture) has again honored our request that foreign research be recognized as susceptible to barter. As a result, some \$2.8 million of barter goods (wheat, corn, etc.) will be made available for the payment of contracts and grants in the European area. These goods are sold on the European market and the proceeds deposited with finance offices in

either Bitburg, Germany, or London, England. The deposited funds are then paid out by the finance offices against appropriate contracts and grants.

Class Determinations and Findings authorizing the negotiation of contracts in the areas of research, Laboratory Support, Laboratory Directors' Fund, sounding-rocket systems, and satellites and payloads were obtained from the Secretary of the Air Force. These Class D&Fs are authorized for use wherever OAR funds are used in one of the designated areas. Their use precludes the necessity of having individual D&Fs, which represents a substantial time-saving factor in procurement processing.

OAR has continued its program to offset the impact on the Nation's international balance of payments resulting from OAR's procurement of essential research programs in foreign countries. This program includes: the intensified negotiation of cost-shared research agreements with foreign scientists and educational institutions; the encouragement of foreign contractors and grantees to purchase supplies and equipment of U.S. manufacture, and the payment of OAR grants and contracts with U.S.-owned excess foreign currencies; an arrangement with the Department of Agriculture to cover grant and contract payments with U.S. dollar proceeds from the sale in world markets of surplus agricultural commodities; and provision for travel by foreign grantees and contractors on aircraft of the Military Airlift Command or on U.S. flag carriers.

Facilities

OAR technical-facility development is an integral part of the Research Program. As such, facilities are considered a fundamental research tool, and should not be considered separate from the Research Program. It is recognized that basic research depends on a flexible use of facilities in the support of individual research efforts.

OAR is making prudent use of facilities now available, and has expanded laboratory and administrative space by using trailers to temporarily absorb increased space requirements. During the past five years, only four OAR construction projects have been funded. The most significant have been the Vacuum

Telescope at Sacramento Peak, New Mexico, and the Special Computation Laboratory currently being constructed at L. G. Hanscom Field, Mass.

Current long-range plans include an energy-conversion laboratory at Wright-Patterson Air Force Base, Ohio; science laboratory for optical physics at L. G. Hanscom Field, Mass; R&D balloon-launching pad at Holloman Air Force Base, New Mexico; technical reports and distribution center at L. G. Hanscom Field, Mass; and a land purchase at North Ipswich, Mass. to support radio astronomy and astrophysics research.

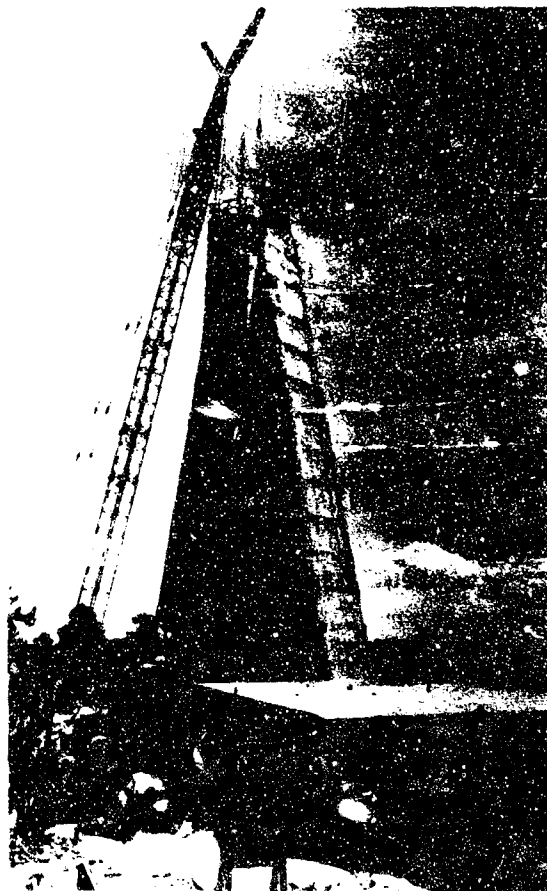
Cost Reduction

OAR reported Command-level validated management-effectiveness savings valued at over \$1,850,000 in the FY-1969 USAF Cost-Reduction Program, thereby exceeding its assigned goal. OAR's consistent participation in this management program has received special recognition. It has been acknowledged that these accomplishments are particularly noteworthy owing to the intrinsic nature of the basic-research mission, and the difficulties encountered in correlating research procedures with standardized program reporting criteria.

The special Tri-Service Study Group, chaired by OAR, and originated by OSD to review the problems associated with basic-research participation in the Cost-Reduction Program, submitted its official report on 4 December 1968. Five (5) recommendations for change were offered for OSD consideration:

1. Assign only current fiscal-year goals (under active consideration)
2. Delete area goals (adopted for FY 1970)
3. Permit scientific savings to be reported in the first fiscal year that quantification can be identified as opposed to first fiscal year of cost impact (under consideration)
4. Permissive review of basic-research submissions recognizing the variances between scientific operations and reporting criteria (not adopted)
5. Reduce administrative load and paper-work volume (under active consideration; revised reporting form applicable in FY 70)

Both OSD and HQ USAF have forwarded highly complimentary letters to HQ OAR for its program leadership, its past and current-program participation, and its contributions to the long-range improvement of the Cost-Reduction Program.



FUTURE OUTLOOK

The weapon systems of the future will develop out of the research being done today and, in many cases, will be dictated by the results of this research. Consequently, it is essential that systematic planning in substantive and fiscal terms be intensified, that long-range goals be identified, and that programs be formulated to meet these goals. To accomplish this, OAR has prepared a *Long-Range Plan for Air Force Research* which sets forth organizational and technical objectives, describes the scientific and technical efforts necessary for their accomplishment, and provides studied estimates of the required resources. Major OAR objectives are as follows:

Organizational Objectives

- Help reduce the lead time between the discovery of new knowledge and its application to the advancement of aerospace technology so as to maintain Air Force operational superiority.
- Maintain in-house laboratories of superior quality to conduct research in selected scientific areas, and continue to enhance the laboratories' research competence and productivity.
- Conduct and sponsor work in exploratory development under the DOD Program Element, Environment.
- Participate in other programs as requested by the Air Force Systems Command (AFSC), and as directed by Headquarters USAF.
- Strengthen the interaction between OAR in-house laboratories and AFOSR, with particular reference to consulting, reporting significant new results, and collaborating on related programs and joint activities.
- Improve the scientific liaison of AFCRL and ARL with other Air Force agencies, and with NASA, DASA, NSA, ARPA, DCS, FAA and others, to contribute to and exploit the Air Force's scientific interface with the national aerospace effort.
- Improve OAR's capability to perform systems and mission analyses.
- Improve OAR's capability to perform research analyses so as to identify technological barriers and promising opportunities for relevant research programs.
- Maintain a European Office of Aerospace Research (OAR) to take advantage of research capabilities

ties in Free Europe, the Near East, Middle East (including India, Burma, and Ceylon), and Africa.

- Within the limits of available resources, continue to support AFSC development activities and the DOD research agencies in Europe.
- In a similar manner, maintain scientific liaison with the Latin-American scientific community, and sustain the exchange of information and mutually beneficial relations between the Air Force and this community.
- Maintain the capability of PFOAR to serve as the focal point for OAR activities at the Air Force Eastern Test Range, and of LOOAR to serve in the same capacity at the Air Force Western Test Range and AFSC's Space and Missile Systems Organization.

Scientific and Technical Objectives

General objectives of the overall OAR effort, by R&D category, are as follows:

Research

- Discover and understand specific phenomena in those disciplines relevant to Air Force technical interests.
- Stay abreast of scientific accomplishments and breakthroughs to preclude technological surprise by others.
- Assure a proper base for the continual development and improvement of Air Force advanced capabilities and technology.
- Provide a quick-reaction technical capability, and an "on-call" pool of technical consultants who can respond rapidly and with flexibility to urgent Air Force operational problems.

Exploratory Development

In general, OAR objectives in exploratory development under the Program Element, Environment, are to develop new techniques for solving specific Air Force problems. In other areas of exploratory development, such as Aerospace Avionics and Ground Electronics, OAR scientists and engineers assist AFSC in the application of research to the enhancement of advanced capabilities.

Advanced Development

The objectives of efforts in advanced development are to provide satellites and sounding rockets for, and balloon support to, Air Force laboratories for upper-atmosphere and space research, and to develop improved Air Force balloon capabilities. In addition, other advanced-development programs may evolve from OAR's exploratory-development efforts during the planning period. While the degree of involvement will depend on the specific program, OAR scientists and engineers will participate actively in selected advanced-development efforts.

Other Research and Development

OAR will continue, upon request, to conduct research for other agencies in those areas in which a unique OAR research capability exists. This work will be compatible with planned scientific and technical objectives.

In facing the future, the character and evolution of OAR itself must be considered. Present plans call for the organizational structure of OAR to remain essentially the same. AFCRL, AFOSR, ARL, FJSRL, and ORA will continue as distinct but co-operating subordinate units.

Emphasis at AFCRL will continue in the environmental sciences. ARL will carry on its work in the physical and engineering sciences. FJSRL will remain in the areas of chemistry, aerospace mechanics, and applied mathematics. ORA will continue its activities in the mathematical sciences. AFOSR will manage extramural efforts in "pioneering research," aimed at developing new or emerging fields of science with probable Air Force significance; in "supporting research," identifiable with known Air Force technological barriers; and in "connecting research," to maintain Air Force contact with broad areas of science supported by others. AFSC laboratories will pursue selected research efforts which support specific in-house exploratory-development efforts.

RESEARCH INFORMATION ACTIVITIES

- The principal *OAR product* is scientific knowledge derived from OAR research and from direct interaction of OAR scientists with the worldwide scientific community.
- The most important *OAR service* is the scientific consultation OAR provides to the other elements of the Air Force and Department of Defense.
- The overriding *OAR objective* is to insure that the world's new scientific knowledge finds practical application in the solution of the technological problems of the Air Force and the Nation as a whole.

These are the fundamental propositions which underlie most of OAR's policies and efforts. In part they explain OAR's emphasis on scientific communications and the exchange of scientific data. They constitute the OAR rationale for the continued and persistent attention given by management to the creation and maintenance of a favorable communication environment, and to continued experimentation with new communication techniques.

OAR's involvement in information-transfer activities spans the spectrum of Government organizations

and consumes appreciable OAR resources. The bulk of OAR efforts in this field is devoted to the analysis and improvement of its internal and external coupling programs. Because of its experience and interest in this area, OAR has also been charged with providing a central point of responsibility for the Air Force's Scientific and Technical Information Program. Together with the other military services and the Director of Defense Research and Engineering, it seeks to develop improved DOD-wide information services essential to the progress of military R&D. It assists the Federal Council on Science and Technology in developing Federal policies for national and international information systems to serve the needs of the entire U.S. scientific community. Finally, OAR supports a sizeable research program in information and computer sciences to obtain a clearer understanding of human- and machine-communication phenomena—a vital element in communication-improvement efforts.

Air Force Activities in Information Transfer and Coupling

In OAR, "coupling" is defined as the transfer of OAR research results to potential users, and the resultant feedback to OAR. The high level of activity in this area results principally from an OAR policy which requires that each scientist employed by OAR, whether in a laboratory or on the scientific staff (as

civilian or military), devote as much as 20% of his activities to coupling. It also reflects OAR determination to serve the Air Force by continually reviewing the climate for coupling activities and by considering new approaches in communication techniques and policies which would improve this climate.

In carrying out this work, OAR continues to pursue a variety of courses, the most important of which is the process of selecting researchers for laboratory work or for extramural research support. Here OAR seeks out those people who are working on the frontiers of their scientific specialty. Through their work, they can stay abreast of scientific progress throughout the world, and can thus serve the Air Force as centers of knowledge for their particular areas. Other courses followed include the use of information-exchange networks active in the scientific community, the solicitation of advice from outstanding members of the scientific community, and the judicious utilization of the professional and trade journals, professional societies, the numerous scientific conferences, abstracting services, and research advisory councils.

Special offices and organizations have played important roles in the operation of OAR research-information-exchange mechanisms. The European Office of Aerospace Research (EOAR) in Brussels continues to serve as our link with research performed in Free Europe, the Near East, Middle East, and Africa. Our Latin American office serves substantially the same purpose in South America. Other active centers include the Scientific and Technical Information Offices at the Headquarters and the laboratories, and the newly established Research Application Offices. While the former organizations have concentrated on the development of tools and techniques for more effective information transfer, the latter have provided significant routes whereby researchers may be alerted to the technological potentialities of particular research, and made aware also of the technological barriers inherent in Air Force R&D needs. In a sense, these offices are OAR's coupling brokers, eventually bringing together the producers and the users of scientific knowledge for fruitful discussion.

OAR publications continue to play a vital role in the transfer of information concerning OAR research activities. The *OAR Monthly Report of Research Proposals*, for example, lists unsolicited proposals for new research received by OAR, and thus informs other Government agencies with respect to research being considered, or already funded, by OAR. This prevents possible duplication of effort, and also alerts potential information users to research efforts likely to be relevant to their interests. The annual *Air Force Research Objectives* encourages the submission of unsolicited research proposals by members of the

scientific community through a delineation of OAR's research goals. The *OAR Research Review*, a bimonthly, alerts Air Force technologists and other potential users to OAR's current research efforts. The *OAR Progress*, an annual publication, reports on the outstanding achievements of OAR research, and also on various managerial aspects. And the *OAR Research Directory* assists in information transfer and coupling by providing the scientific community with a listing of OAR current research projects and the names, addresses, and telephone numbers of OAR key personnel.

Many of these mechanisms provide more than one communication channel. For example, symposia and conferences help us to learn about recent discoveries and the progress of current R&D efforts. They are also effective platforms for the exchange of opinions on the desirability of new work projects. Another characteristic of many research communication channels is their redundancy. This provides some assurance that, when one channel fails, another may be expected to carry the message. Most effective communication mechanisms operate essentially on a person-to-person basis, providing instantaneous feedback and mutual clarification.

Specific instances of OAR coupling achievements resulting from the above approaches are too numerous and varied for detailed description in this type of report. However, a few samples from this year's coupling activities may be mentioned:

- AFCRL's Environmental Consultation Service (ECS) was formally established to service the Air Force as a whole. By formal agreement with the 6th Weather Wing, 13 staff meteorologists of the Air Force Systems Command have served to augment and expedite requests for AFCRL's consultation services. As a result, the number of requests in the past year increased markedly, with 43 requests from AFSC divisions, centers and contractors alone. Problems requiring consultation involved questions of weather avoidance, weather effects on missile tests, criteria for the evaluation of ground-control-radar work statements, auroral backgrounds, the diffusion of toxic propellants, and the attenuation of satellite signals by clouds and precipitation.

- Two scientists at AFCRL and one scientist at the Scripps Institute of Oceanography assisted Headquarters USAF to determine the most plausible attrition estimates for B-52 aircraft considered for a special mission in Vietnam. The nighttime

visibility of a B-52 at low altitude was determined to be the most critical and least-understood parameter. This application of accumulated knowledge to a practical operational situation contributed significantly to subsequent operational decision-making.

- Scientists of ARL's Chemistry Research Laboratory actively assisted a study group at AFSC's Aeronautical Systems Division to develop an effective method for using the emergency supply of oxygen to pressurize cockpits normally pressurized with an oil-contaminated engine air supply. This consultation should have significant impact on future inflight emergency procedures.

- AFOSR completed a study at the Franklin Institute on the potential uses of materials with low ductility (brittle materials). In the process, it also determined the need for additional research to make economical and operationally feasible use of these materials. As a result, AFOSR has opened a whole new field of scientific inquiry under the name of thrustics.

- Members of HQ OAR, together with scientists from ARL and ORA, have consulted with AFSC concerning research needs and technological problems involved in magnetohydrodynamics. This consultation should permit the Air Force to achieve a better understanding of the potential resulting in this technology, as well as a more accurate assessment of its application for airborne operations.

Providing a Focal Point for Air Force STINFO Responsibilities

As a result of its heavy involvement in, and emphasis on, the interchange of scientific information, OAR developed considerable expertise in a variety of scientific-and-technical-information activities. Consequently, in 1967, its Office of Scientific and Technical Information was charged by HQ USAF with the responsibility for providing an Air Force focal point for the coordination of all scientific and technical information (STINFO). This focal-point responsibility embraced such functions as improving Air Force-wide scientific-communication processes

and services, technical libraries, specialized information-analysis centers, and the publication and dissemination of technical documents. Progress has been achieved in at least three areas: program visibility, policy direction, and innovations.

An important step in making the Air Force STINFO program visible and comprehensible was through the publication of the *Air Force Scientific and Technical Information Roster*—a directory of Information Offices, S&T Liaison Offices, contractor data-management focal points, technical libraries, information-analysis centers and specialized information activities. In addition, a program examination was conducted for the President's Office of Science and Technology. The results of this examination are being published for wide distribution, and will highlight the essential features of the program and pinpoint the problem areas which require management's attention.

Aside from reviewing and updating the policies and regulations which govern the execution of the STINFO program, OAR's Office of Scientific and Technical Information also concluded a two-year experiment on the selective dissemination of information. The objective was to find the most economical and useful means for alerting technical people to new technical developments arrived at by the Department of Defense and other Government agencies. The resulting selective document announcement system, brought forth in cooperation with the Department of Commerce's Clearinghouse for Federal Scientific and Technical Information, is known as CAST (Clearinghouse Announcements in Science and Technology). This program has been so successful that, since July 1968, it has been extended to the general public.

Contributions to the Development of Government R & D Information Policies

In the past year, OAR people have been called upon not only to participate in evaluating the proposed policies of the Director for Defense Research and Engineering, but also to assess the STINFO programs of other Government agencies. Thus, they have assisted in the evaluation of selective-dissemination programs of the Department of Interior and in consultations for the National Archives and Records Service of the General Services Administration; they have served as members and chairmen of panels of the Committee on Scientific and Technical Information (COSATI), Federal Council on Science and Technology, and they have been of assistance to the scientific and technical staff of the President's Office of Science and Technology. Of particular importance is the recent OAR contribution to a special COSATI panel established to identify the

impediments to the effective dissemination of technical information. The resulting study, entitled "Recommendation for Improving the Dissemination of Federal Scientific and Technical Information," is currently being reviewed by the Executive agencies and the President's Office of Science and Technology.

OAR's Director of Scientific and Technical Information chaired this panel. It is anticipated that, if approved and implemented, the study will result in desirable changes in Federal policies and regulations pertaining to public access to scientific-and-technical documentation and data.

SCIENTIFIC PROGRESS FY 69

SCIENTIFIC PROGRESS IN FY 69

The brief articles on the following pages describe some of the research accomplished by OAR during Fiscal Year 1969 in areas of significance to the Air Force. The work includes both contributions to basic knowledge and applications of research vital to the steady technological progress of the Air Force. Although these articles treat only a fraction of the research carried out in OAR's own laboratories and in the laboratories of its contractors and grantees, they do provide some idea of the importance, variety and scope of the whole OAR research program. This will be immediately apparent from the various DoD Elements and Subelements (shown below) encompassing OAR's diverse research efforts.

Those desiring additional information on the research accomplished should consult the comprehensive Bibliography following this section.

DEFENSE RESEARCH SCIENCES

Subelements:

General Physics

Nuclear Physics

Chemistry

Mathematical Sciences

Electronics

Materials Research

Mechanics

PROGRAM ELEMENT 61102F

Energy Conversion

Terrestrial Sciences

Atmospheric Sciences

Astronomy and Astrophysics

Biological and Medical Sciences

Behavioral and Social Sciences

ENVIRONMENT

AEROSPACE AVIONICS

GROUND ELECTRONICS

SATELLITES, BALLOONS, AND SOUNDING ROCKETS—SABAR

PROGRAM ELEMENT 62101F

PROGRAM ELEMENT 62403F

PROGRAM ELEMENT 62702F

PROGRAM ELEMENT 63404F

NEW GRAVITY TEST POSSIBLE*

A recent study of two competing gravitational theories indicates that there is a possibility of using existing equipment to determine which one is valid. The competing theories in question are (1) Albert Einstein's general theory of relativity—the gravitational theory that has been almost universally accepted since its proposal in 1916—and (2) a scalar-tensor theory of gravity that has received considerable attention since 1961.

Drs. Jeffrey H. Winicour and David C. Robinson** of the General Physics Research Laboratory, ARL, show that the theories differ in their predictions about the kinds of gravity waves that should be given off during the formation of neutron stars. However, theorists believe they are formed when ordinary stars no longer have enough fuel to keep from collapsing under the force of their own gravity.

Writing in *Physical Review Letters*, (see Reference 1 in Bibliography) a publication of the American Physical Society, Drs. Winicour and Robinson show that gravity-wave detectors recently built by Dr. Joseph Weber of the University of Maryland (two at the University of Maryland and one at the Argonne National Laboratory, Chicago) may be sensitive enough to measure the type of wave generated when a neutron star forms. This may enable physicists to determine which theory made the correct prediction.

Because neutron-star formation is relatively rare, and since Dr. Weber's detectors were not designed to distinguish between the kinds of radiation predicted by the two theories, there is only a slim chance that a test can be made in the near future. However, the possibility of experimentally checking gravity theory and neutron-star theory makes even this slim chance seem attractive.

The discovery of pulsars early in 1968 gives added interest to the paper by Winicour and Robinson. Recent evidence indicates that the 25 or so pulsars that have been discovered may be neutron stars. Therefore, any work that increases our understanding of gravity and neutron stars can also increase our understanding of pulsars.

The historical background behind these develop-

ments may be traced back to the account of gravitation published by Isaac Newton in 1687, as based upon traditional Euclidean geometry, and a calculus that Newton invented in order to work out his theory. In the middle of the 19th century Georg Friedrich B. Riemann generalized Euclidean geometry, and it was this generalization that Albert Einstein used, along with a tensor calculus, to develop the general theory of relativity.

There are several alternate approaches to gravitational theory, including one that involves the use of a scalar calculus in addition to the tensor calculus. Several relativists, including Einstein, have considered scalar-tensor approaches to gravitation. In 1961, Dr. Carl Brans of Loyola University in New Orleans, and Dr. Robert Dicke of Princeton University proposed a scalar-tensor theory that is now receiving considerable attention.

The observational differences predicted by general relativity and the Brans-Dicke theory are difficult to measure. Since 1961 Dr. Dicke has conducted one experiment that some physicists have interpreted as showing a difference, and several experiments, designed to distinguish between the theories, are now in progress. However, there is no experimental work that unequivocally shows a difference in the two approaches to gravity.

Contained within the equations of general relativity is the prediction that an oscillating object should generate gravitational waves. An analogous situation is the generation of electromagnetic waves by an oscillating charged body.

In electromagnetism, a body with one set of charged poles can produce dipole radiation. Higher orders of radiation (quadrupole, octapole, etc.), are possible if more than one pair of charges are present. According to general relativity, only quadrupole or higher orders of radiation are possible; but the scalar component of the Brans-Dicke theory allows monopole radiation.

Compared with electromagnetic radiation, gravitational radiation is quite weak, and it is only recently that technical advances have opened up the possibility of detecting it. Dr. Weber's detectors are designed to detect radiation (of the Einstein variety) from reasonable astronomical sources such as rotating stars or collapsing supernovae. Since early 1967, the two gravity-wave detectors that he has at the University of Maryland have measured about one "event" per month. So far there has been no definite way of

*Excerpted from an American Institute of Physics news release written by Science writer Bob Holcomb.

**Dr. Robinson is a National Academy of Sciences Postdoctoral Resident Research Associate.

knowing if these are gravity waves; but it is likely that at least some of Dr. Weber's "events" are the result of gravitational radiation.***

In their article, Drs. Winicour and Robinson show that the radiation produced when neutron stars are formed from collapsing supernovae can be detected more easily if the Brans-Dicke theory is correct. That is, the monopole radiation is stronger than the multipole radiation predicted by general relativity. Definite proof of monopole radiation, and hence of the Brans-Dicke theory of gravitation, would require a combination of circumstances that is somewhat unlikely at the present time.

***Recent coincidence measurements between detectors at the Argonne National Laboratory and the University of Maryland now give excellent evidence for advanced events due to gravitational radiation. See J. Weber, *Physical Review Letters*, 22 (16 June 1969), 1320.

The collapse of supernovae to form neutron stars is relatively rare. Only 3 observations of exploding supernovae have been recorded in all history (in the years 1054, 1572, and 1604). It is possible that not all supernovae are observed; but even the most generous estimates of neutron-star formation give a rate of only 1 every 20 years.

The oscillations that produce the gravity waves are damped out in about one hundredth of a second, so the collapsing star must be observed during this time. Catching such a rare event at present is unlikely, but this situation may not continue. Since little is known about neutron stars (or pulsars), there is the possibility that future information will enable astronomers to know when and where to look for the formation of neutron stars by supernovae collapse. It is also possible to build gravity-wave detectors that are more sensitive to the kind of radiation expected from neutron-star formation.

general physics

A THEORY OF SOLAR FLARES

During the past three years, Professor Peter A. Sturrock and others at Stanford University have been working on a theory of solar flares. (See Reference 1 in Bibliography.) A model has been developed which is based on the knowledge that a substantial fraction of the magnetic-field lines originating at the solar photosphere are open-field lines, penetrating far into interplanetary space. The contrary assumption, that all magnetic-field lines close within the near neighborhood of the sun, is incompatible with the existence of the solar wind. The magnetic-field configuration shown in Figure 1 is representative of the topology of magnetic-field lines above a simple bipolar active region, taking the above fact into account. A certain fraction of the magnetic flux linking the two regions of opposite polarity is linked by closed magnetic-field lines, while another fraction is associated with open magnetic-field lines. The open-field lines provide a channel for the escaping coronal gas which constitutes the solar wind. An important property of this field configuration is that the boundary between the two open flux tubes must carry a sheet current, since there is a sharp reversal in field direction at the surface. This field configuration incorporates free energy which can be released without changing the connection of magnetic-field lines at the photosphere. Since this field pattern contains open field lines, there is no difficulty in understanding the fact that Type-III radio bursts may be caused at the very beginning of a flare by streams of electrons traveling radially outward from the sun.

How was the energy in this configuration built up, and what was the source of the energy? The existence of the corona is due to the fact that the photosphere generates high-intensity sound waves which travel through the chromosphere and into the corona. The sound waves are dissipated by one or more processes, and it is this dissipation of energy which heats the chromosphere and the corona to temperatures far above the temperature of the photosphere. This energy supply is responsible also for the energy necessary to drive the solar wind. This means that the acoustic energy flux which propagates along the closed-field lines is used entirely in heating the corona; by contrast, the acoustic energy flux which travels along the open-field lines goes partly into heating the corona and partly into driving the solar wind. In consequence, the density and temperature in the closed-field regions should be higher than the corresponding values at the same height in the open-field region. Hence, in the region of the "Y-type neutral line," shown in Figure 1, the pressure is higher just inside the cusp (the region of closed-field lines) than just outside the cusp (the region of open-field lines). The result of this pressure difference should be that closed-field lines are driven into the sheet-like aperture between the two open flux tubes. This expulsion of field lines provides a mechanism for progressively enlarging the fraction of magnetic flux which is associated with the open-field region. Hence it is a way of building up the free energy of this configuration. We now see that the free energy of this

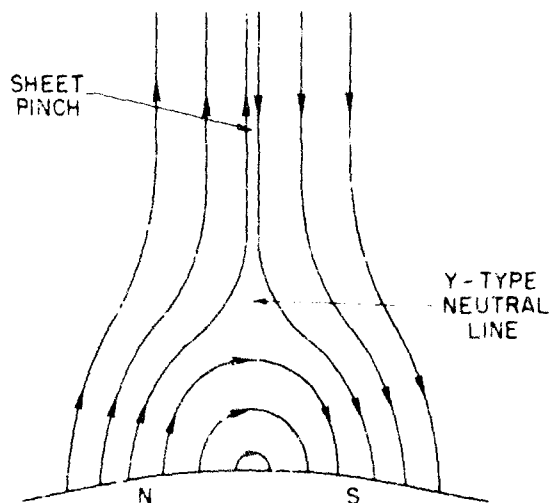


Figure 1. Schematic representation of magnetic-field pattern above a bipolar magnetic region, showing the transition from closed-field lines at low heights to open-field lines at great heights, involving Y-type neutral line and sheet pinch.

field configuration may be derived from the non-thermal energy flux which is responsible for heating the corona.

What is the mechanism for the sudden release of energy in flares? The nature of solar flares and the realization that the stored energy is magnetic have led to the view, which has been established for many years, that the energy release is intrinsically an electromagnetic process. Since the flare is an explosive event, the energy release must be effected by a plasma instability. The instability which is relevant to the present model is the "tearing-mode" instability (See Reference 2 in Bibliography) which leads to a reconnection of magnetic-field lines, providing a mechanism by which the open-field lines may rapidly become closed. As a result of the very high conductivity of the coronal plasma, the neutral sheet will be very thin, having a scale of less than 100 meters. The rise time of the instability is correspondingly short, and can explain the 1-second time scale of Type-III bursts. The reconnection of field lines occurs progressively. As one pair of field lines are reconnected, they become subject to forces (mainly magnetic tension) which move them away from the region in which reconnection is taking place, so that a new pair of field lines is then reconnected. This is indicated schematically in Figure 2.

How does this sudden release lead to the observed properties of the solar flares? Following flare action, the field pattern shown in Figure 1 takes on the form shown in Figure 3, in which a large fraction of the open-field lines have been replaced by closed-field lines. Since energy has been released during the

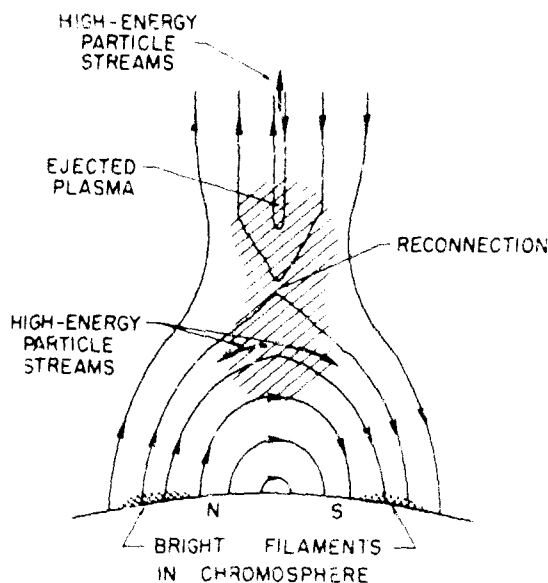


Figure 2. Schematic representation of reconnection of magnetic field lines during a flare, showing ejection of plasma and heating of chromosphere by particle streams to form two bright filaments.

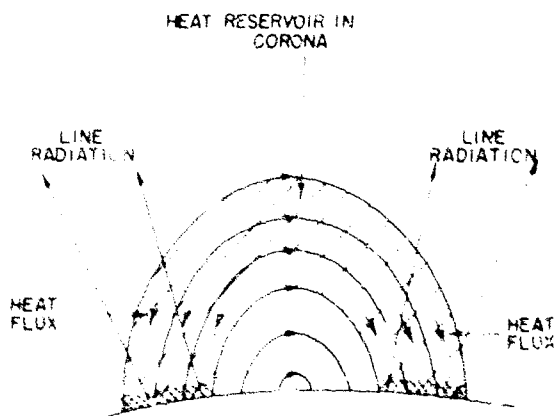


Figure 3. Schematic representation of the decay stage of a solar flare, showing the trapped high-temperature plasma in the corona, the heat flux to the chromosphere, and enhanced radiation from the chromosphere.

reconnection process, a large amount of energy is now stored in the trapped coronal gas. This gives rise to an increase in temperature of the trapped plasma to about 10^7 °K, and also an increase in density above normal coronal values, since an increase in temperature involves an increase in scale height. This mass of hot plasma would constitute a strong source of soft X rays, and would explain X-ray observations of solar flares. The main mechanism for energy loss by this hot plasma is by thermal conduction down to the

chromosphere, where the energy will be lost by increased radiation, primarily in strong chromospheric lines such as H α . This chromospheric radiation will continue until the coronal gas has cooled to normal coronal temperatures. This represents the "decay phase" of a solar flare. Following reconnection, the bipolar flux tube which extends into interplanetary space has been reconnected so that the field lines are no longer tied to the photosphere. The

plasma in this flux tube now experiences forces (mainly magnetic tension by the open magnetic-field lines) which "catapult" the plasma away from the sun. The ejection of a mass of plasma from the flare region enables one to understand how a solar flare can give rise to a magnetic storm on earth. The shock front which would form in advance of the ejected plasma cloud provides a likely explanation for a Type-II radio burst.

general physics

GEL GROWTH OF CUPROUS CHLORIDE, AN ELECTRO-OPTICAL MATERIAL

A significant potential application of the laser is in communications. Before this can be achieved, however, efficient means for the modulation and demodulation of the laser beam are required. Since the frequencies that must be applied are much higher than can be attained by present methods of mechanical modulation, other means must be devised. A possible means for the phase modulation of lasers is the utilization of crystals which change their refractive index in response to an applied electric field. The change in the index of refraction causes a change in the velocity, hence, the phase, of the laser beam passing through the crystal.

One of the most promising materials that can be used for laser modulation is cuprous chloride. It has many desirable and necessary characteristics. For example, it has a high transparency, out to about 20 microns; its dielectric constant is 8; the dielectric loss tangent is 0.01 to 0.0004; and its energy gap is in the range of 3eV. However, until recently, all techniques used in an attempt to grow cuprous-chloride crystals have produced crystals unsatisfactory for practical use.

By using a novel adaption of the gel-growth method, Dr. Alton Armington of the Solid State Sciences Laboratory at AFCRL has succeeded in growing satisfactory cuprous-chloride crystals, at room temperature. In this investigation, AFCRL scientists developed a complex dilution method that permitted the growth of materials that are highly insoluble under normal conditions. In this method, the material to be grown is complexed with a reagent in such a manner that dilution will cause the

complexed material to precipitate out of the solution. An example of this type is the formation of a solution of cuprous chloride complexed in hydrochloric acid.

Experimentally, 5 liter reservoirs were used with 40-mm tubes in a set of experiments to produce larger crystals. Crystals 8 mm long were produced in about 2 months using a growth container that was maintained at $23 \pm 1/2^\circ\text{C}$ in a water bath. While constant temperature did not seem important in the smaller runs, it did seem to be important when larger crystals were grown.

The largest clear colorless crystals grown to the present time are 8 mm on an edge, with no visible evidence of voids or inclusions. Mechanically, the material is quite soft, having a hardness of 9.86 Kg/mm² as measured with a pyramid indenter and a 50-gram load. Electron microprobe measurements indicate a uniform stoichiometric concentration of copper and chlorine in all of the crystals tested. Transmission data for a cuprous-chloride sample 1 mm thick shows that the crystal transmits in the range from about 0.4 to beyond 20 microns. While the transmission agrees with previous data, that there is a cutoff at about 0.4 microns, the AFCRL material transmits further into the infrared than the previously reported cutoff at 18 microns. Measurements of the refractive index as a function of the wavelength in gel-grown crystals show it to be relatively constant throughout a large region of the infrared.

Some of the crystals grown were furnished by the National Bureau of Standards, under an AFCRL Contract. Successful modulation of a helium-neon laser beam has been achieved.

DISPERSION AND STABILITY OF IONIZATION WAVES IN A DISCHARGE PLASMA

An investigation of the dispersion and occurrence of convective and absolutely unstable ionization waves (moving striations) in the positive column of low-pressure glow-discharge plasmas has been conducted by Drs. Alan Garscadden and Peter Bletzinger of the Plasma Physics Research Laboratory, ARL. Although these waves have been observed and described by many researchers, only in the past few years has an adequate theory been developed to explain the experimental observations and measurements. (See References 1 and 2 in Bibliography.)

The glow discharge in rare gases often contains backward-wave (BW) moving striations in the pressure range of 0.5 to 10 torr. At higher pressures (p) and

higher current (I), these waves are attenuated. As p or I increases, there is a partial contraction of the positive column until, above a certain critical pressure or current, the discharge changes abruptly into a well-defined constricted form, with moving striations often present. Experiments in argon and neon show that the onset of the constriction proceeds as a BW from the cathode at lower pressures, but changes to a forward wave (FW) from the anode at higher pressures. Figure 1a shows the disturbance excited in an argon discharge at 9.2 torr. In the high-current (62-ma) region, an absolute BW instability is excited; in the low-current (20-ma) region, a convective BW exists. At intermediate argon pressures, discharge

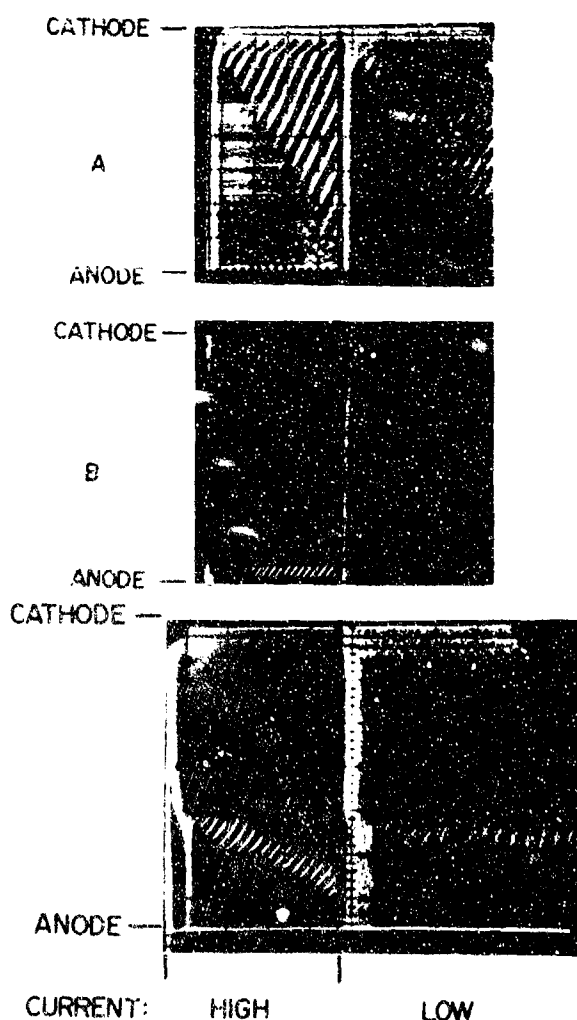


Figure 1. Excitation of ionization waves in argon. Time base, 2 msec/large div., cathode at top of space-time display. Time increases left to right.

a. Pressure, 9.2 torr; current, 62 ma (high), 20 ma (low).
b. Pressure, 23 torr; current, 60 ma (high), 10 ma (low).

Figure 2. Excitation of ionization waves in neon. Time base, 2 msec/large div., cathode at top of space-time display. Time increases from left to right. Pressure, 65.5 torr; current, 90 ma (high), 60 ma (low).

conditions were obtained such that constriction and ionization waves (absolute instabilities) developed simultaneously from both electrodes - Figure 1b, pressure 23 torr. Near these conditions, the results were sensitive to the current modulation amplitude. At high amplitudes, two BW packets developed from the cathode. It was also noted that, although the BW was correlated with the current pulse, the FW was not always so. When both waves exist, then the electron temperature relaxation length, a^{-1} , is bounded; i.e., $k_{FW} < a < k_{BW}$, where k is the wavenumber. At 25 torr and 80 ma, $a^{-1} \approx 0.5$ cm. Above about 35 torr, the discharge constricts only from the anode. In neon the results were similar, except that a higher pressure or current was required for the transitions.

A recording was obtained in neon, Figure 2 where, in the low-current period at 65.5 torr, the group velocity of the excited wave was zero. The disturbance oscillates in time, but does not propagate.

Theoretical results are summarized in Figure 3,

where the stability areas are shown in parameter space α - β , where α and β are determined from the properties of the discharge. It was found that α is approximately proportional to $p^2 R^2$, where R is the discharge-tube radius. The points are those of different experiments. A model discharge ($\beta = 0.63$ and independent of p and l) would only exhibit BW ionization waves. This agrees with the observation that FW ionization waves were only observed in association with constriction (#3). Also as indicated in Figure 3, it is easier to obtain a BW convective region at lower α (#1, #2). At $\alpha = 0.25$, it is possible to make the transition from stable to unstable without a convective region. The abrupt constriction or occurrence of ionization waves throughout the column can be produced by a discontinuous change in β (e.g., by current modulation), or at this value of α . It was noted that the FW convective instability area is very limited; therefore, the experimentally observed FW striations will often be absolutely unstable.

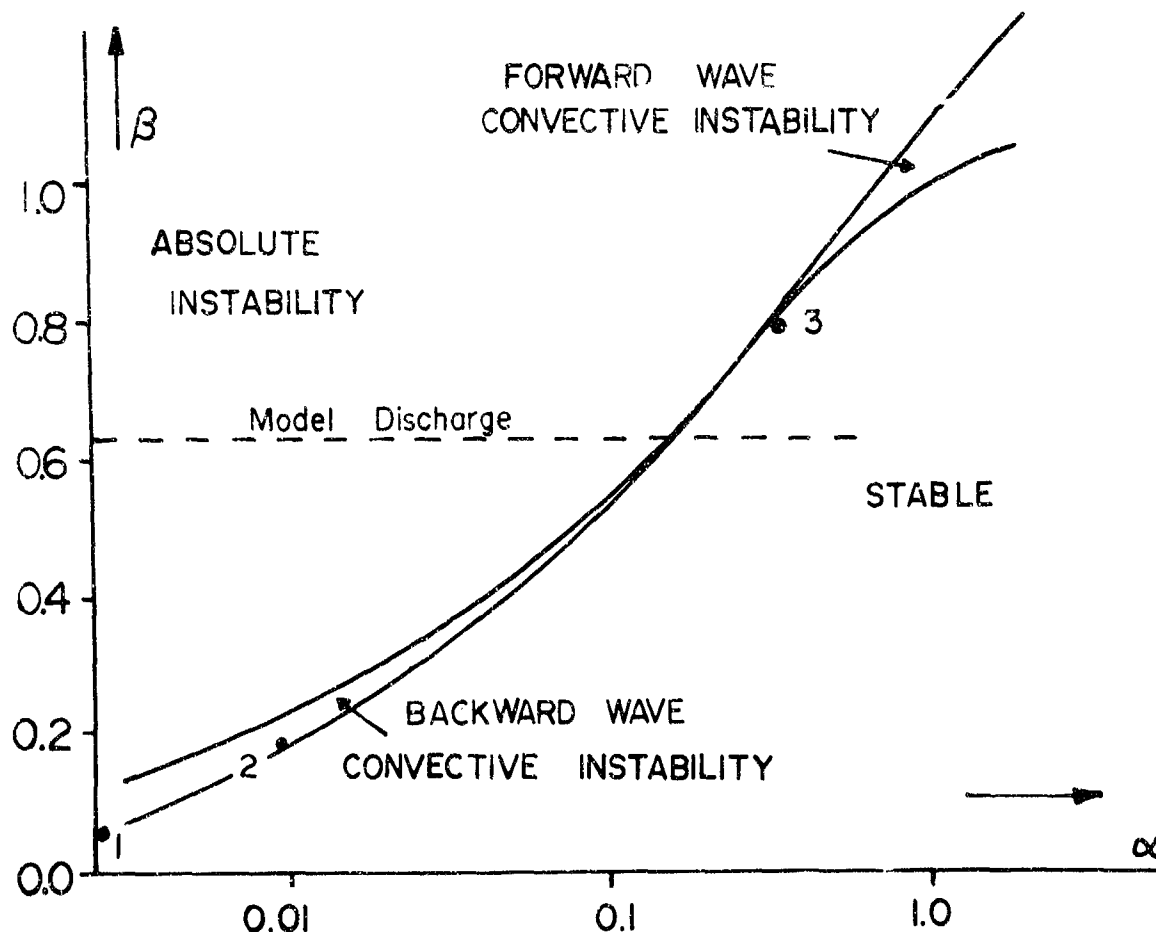


Figure 3. Stable and unstable ionization wave regions as a function of two discharge parameters, α and β .

Experiments: # 1 - neon
2 - argon-mercury
3 - constricted argon.

DIELECTRIC CONSTANTS OF MATERIALS IN THE FAR-INFRARED REGION

Professor P. D. Coleman and his colleagues at the University of Illinois, under AFOSR sponsorship, report new measurements of dielectric constants of materials in the microwave-optic region. These make use of recently developed molecular lasers which provide over 100 lasing lines from 16 to 774 microns, and experimental carcinotron tubes which, from the microwave side, extend the wavelength range down to sources from both the optical and microwave sides of the spectrum. Detectors suitable for use in this region have likewise been developed. These include photoconductive and semiconductor diode detectors.

The measurement schemes used to determine the dielectric constants in this region are adaptations of older optical methods used in regions of shorter wavelengths. These involve the reflection and transmission of polarized plane waves through sheets, prisms, lenses, etc. of the materials to be measured. A measurement technique used with the carcinotron tube in the 0.35-to-4 millimeter-wavelength region is shown in Figure 1.

The measurement arrangement for use with the molecular-laser source in the range 0.016 to 0.774 millimeters is shown in Figure 2.

Single-frequency operation of the laser is achieved by using a rotatable reflection grating in place of a flat mirror in the laser resonator. The radiation is polarized by means of a wire grid rather than a Brewster angle window.

These new methods, along with other schemes previously reported, provide techniques, sources, and detectors suitable for the measurement of dielectric constants, at almost any given wavelength from 30 to 3,000 microns, of materials which can be obtained in chip or sheet form. In the 280-774 micron range, sources and methods overlap and thus provide a cross check on one another.

Knowledge of the dielectric constants of materials in the far-infrared is necessary for the design of devices, for the selection of materials for Brewster windows, lenses, detector windows, beam splitters, laser windows, mirrors, polarizers, and for host

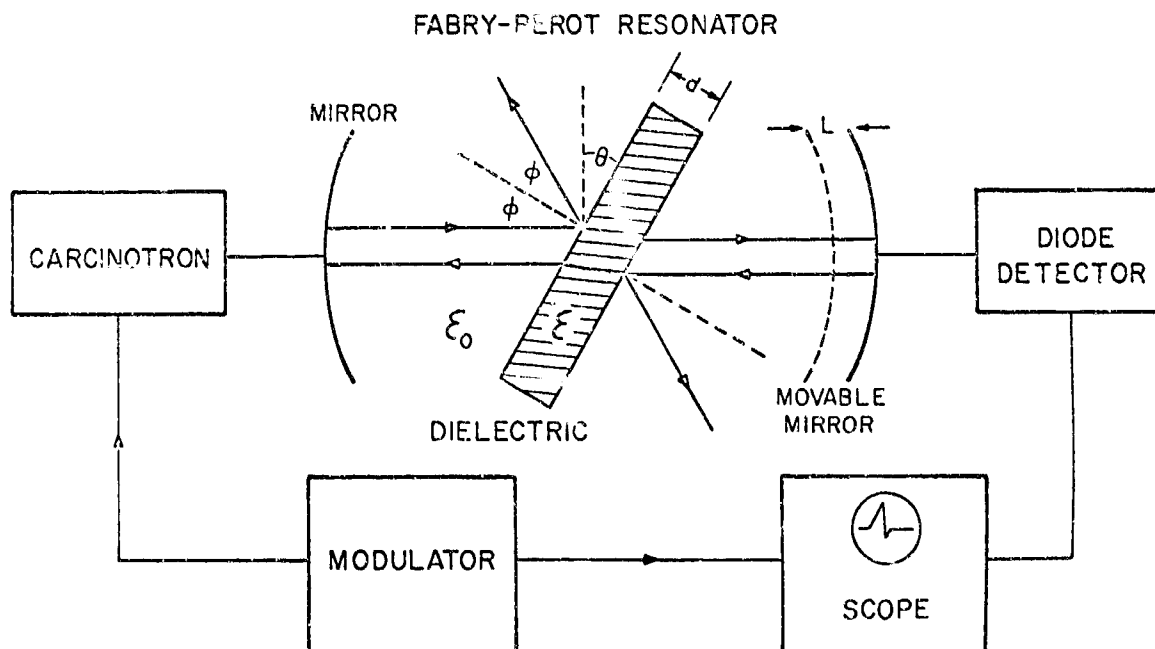


Figure 1. Carcinotron-Fabry-Perot resonator method.

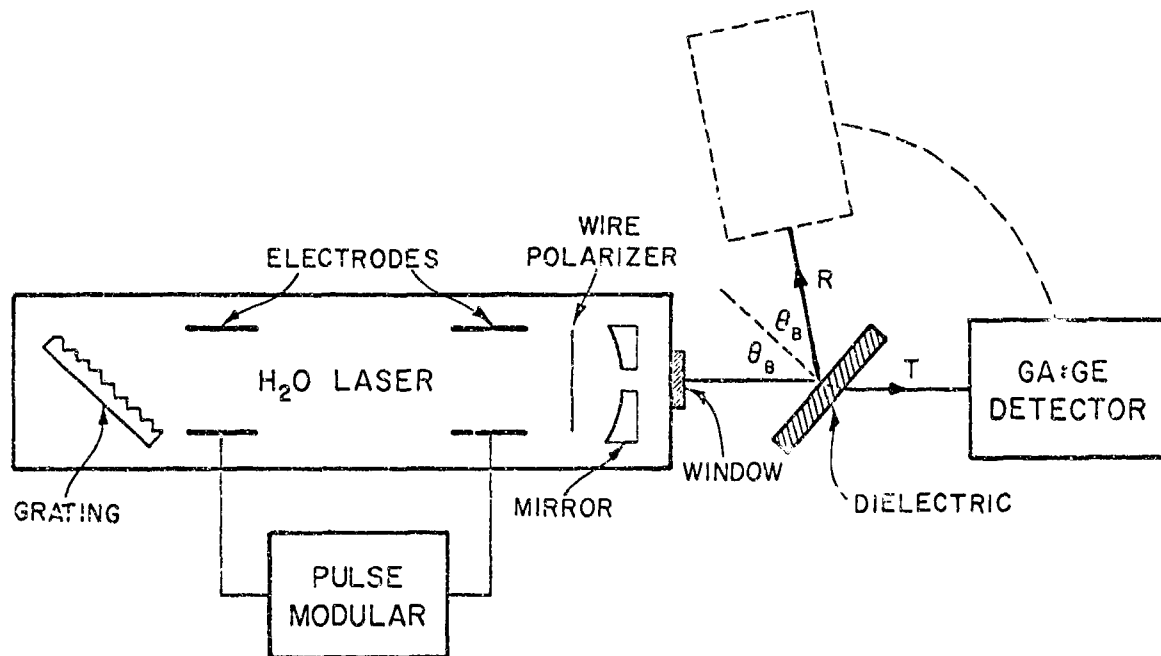


Figure 2. Molecular laser-Brewster angle method.

materials for dopants. The last is of interest to those who are developing laser devices. The techniques can be extended to the study of resonances, photoconductors, anisotropic and electro-optic materials, non-

linear effects, and optical effects in liquids. With these new coherent sources and detectors, it is expected that investigations in the far-infrared will proceed rapidly.

general physics

CdS SOLAR CELLS

Solar-cell power systems have been the power source for almost all long-duration spacecraft that have been launched by the United States. It is likely that they will continue to occupy this dominant position for many years to come. Silicon solar cells are the only type of solar cells that have been useable for power generation until quite recently, when thin-film cells became feasible.

One of the early programs in the Solid State Physics Research Laboratory concerned an investigation of materials for high-temperature diodes. This program, which was carried out under the direction of D. C. Reynolds, led to the development of the CdS solar cell, which is now approaching the application stage. The cell is a thin-film configuration consisting of evaporated CdS on a plastic substrate. The barrier layer is produced by plating Cu_2S over the CdS film. The Cu_2S is of a high-conductivity P-type material,

and the CdS film is of a high-conductivity N-type material.

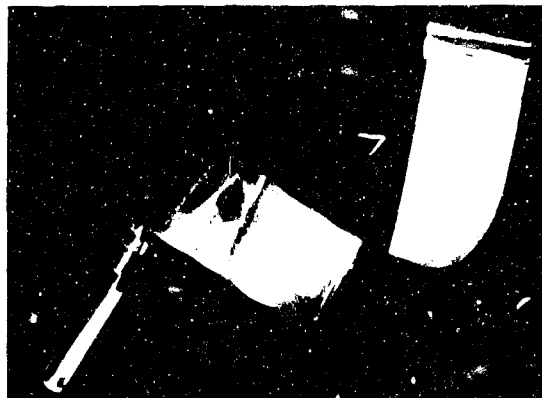


Figure 1. Sample of flexible thin-film cells.

Orbital flight tests are currently being made on the cells. A panel of cells has been in orbit on the OV1-13 satellite for over a year. These cells have shown essentially no degradation. In March 1969, another panel was launched on the OV1-17 satellite. Balloon-flight tests have also been conducted. Due to their flexibility, light weight, radiation resistance and low cost, they have great potential for auxiliary-power sources for both balloons and satellites.

Work is being continued to increase the efficiency and stability of CdS thin-film solar cells. Most of the work is concerned with improvements in the formation of the barrier layer and includes treatment of the CdS film prior to the formation of the barrier layer, variations in the barrier-formation process, and treatment of the film and barrier after formation of the barrier.

general physics

ELECTROMAGNETIC PROOF LOADING OF BONDED AIRCRAFT STRUCTURES

Modern aircraft can not yet fully utilize the advantages of epoxy-bonding techniques because no nondestructive test method exists. Epoxy bonding offers substantial advantages over the conventional technique of riveting by avoiding local stress concentrations, by providing mechanical damping, and by allowing the use of continuously graded honeycomb-filled laminations which offer substantial weight reduction. Bonding is in fact being successfully used at present, but only in noncritical areas. Its use in primary and secondary structures must await the development of a reliable nondestructive testing method applicable during manufacture and in-service inspections.

In the course of extensive efforts to solve this problem, the Boeing Company has found several feasible methods for detecting no-bond defects, or cavities in the bonding layer, by thermal and acoustical means. A proper test, however, must be capable of detecting not only a no-bond defect, but also weak-bond defects which have only a certain fraction of the nominal bond strength. To do so it is necessary to subject the bonded panel to a proof-loading force, a traction force of known magnitude which is capable of producing an observable deformation, either elastic or permanent, if the local bond strength is below a predetermined value.

Mr. Karl Hansen of the Boeing Company has succeeded in applying proof-loading forces to test pieces, electromagnetically, by passing substantial electric-current pulses through bonded test panels and subjecting them simultaneously to a pulsed magnetic field perpendicular to the current and in the plane of the panel. The method is not applicable in practice, however, because the required currents (several thousand amperes per centimeter) cannot be injected without causing contact damage, and the laminations to be tested in subassemblies or complete aircraft are not electrically insulated. Boeing therefore ap-

proached the Francis Bitter National Magnet Laboratory at MIT to see if a non-contact electromagnetic technique could be devised.

Unfortunately, the force exerted by a pulsed magnet on metal, caused by the interaction between the magnetic field and induced eddy currents, is always directed away from the magnet coil. However, Dr. Henry Kolm of MIT had previously conceived a more sophisticated technique involving the application of two separate pulsed magnetic fields, a technique which is inherently capable of generating a traction force. A fast pulse is timed to coincide with the peak of a slow pulse, which freely penetrates the skin, and is of such a polarity that the skin currents it induces, reacting against the penetrating field, produce a net traction force.

As a feasibility study, Drs. Henry Kolm and Bruce Montgomery, members of the staff of the Francis Bitter National Magnet Laboratory, used an available continuous six-inch-caliber Bitter solenoid to simulate the slow pulsed field and achieved the first successful operation in December 1968. Figure 1 shows this system installed in the Bitter solenoid, including the instrumentation located on a balcony above the solenoid magnet.

The fast-pulse coil in this system is coaxial with the Bitter magnet, and has an oval cross section capable of accommodating test panels up to 3 inches wide. The system is capable of applying average proof-loading impacts up to 100 atmospheres and transmitting kinetic energy amounting to 0.15 joules per cm².

The next step will be the prototype development of an industrial proof-loading machine capable of testing extended panels or entire aircraft accessible only from the outer surface. Figure 2 shows the geometry of a traction coil to accomplish this. The fast-pulse coil, a flat pancake spiral located nearest

the skin, is decoupled from the outer slow-pulse coil by a metal flux shield. It is estimated that a fast-pulse energy of 10 kilojoules will suffice to proof-load a 4-square-inch area to 100 atmospheres.

If it proves as successful as preliminary tests indicate, this device may make possible the most significant innovation in airframe construction since the advent of the metal aeroplane.

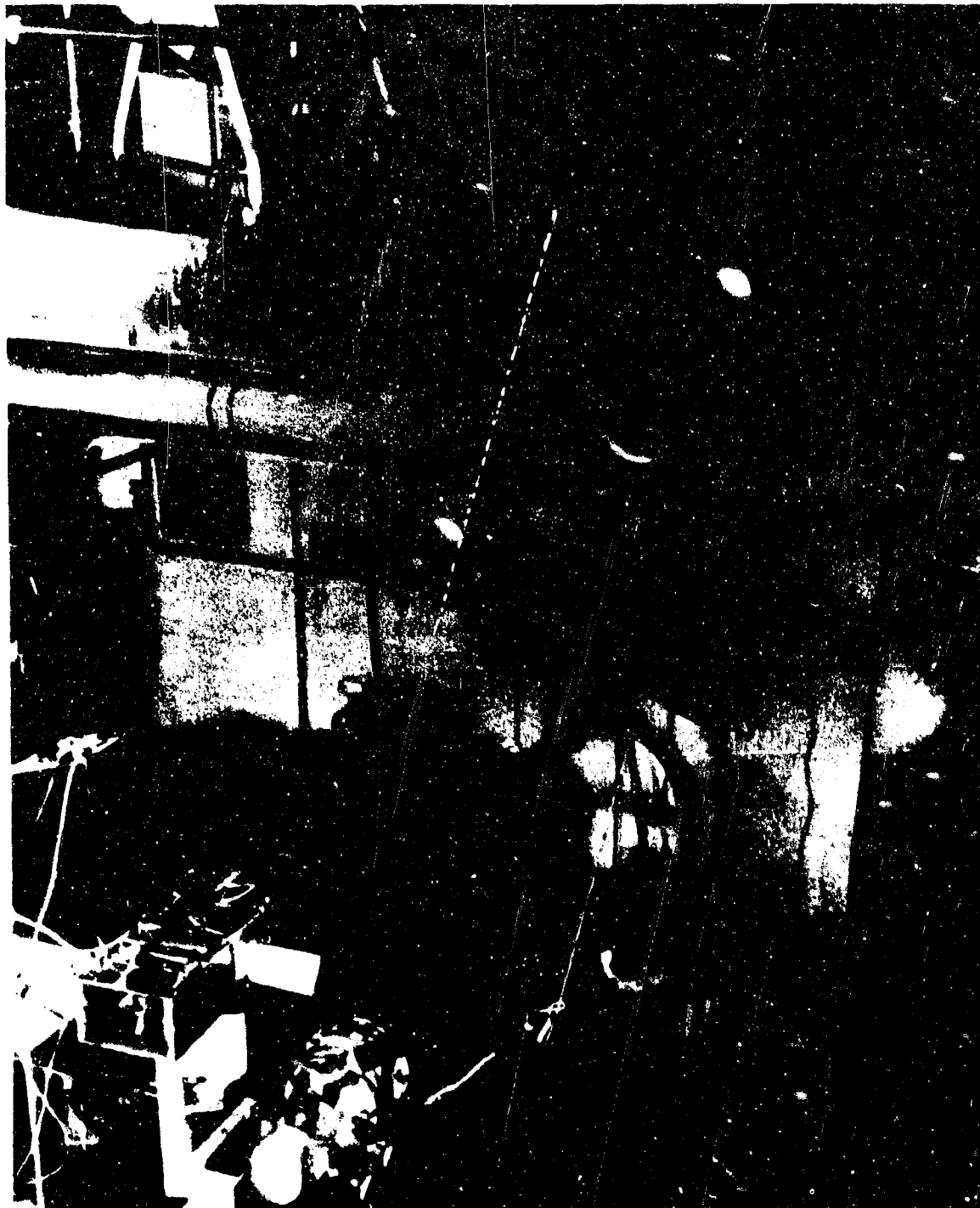


Figure 1. Electromagnetic feasibility system for studying the proof loading of bonded aircraft structures. The system is installed in a six-inch-caliber Bitter solenoid to simulate the slow pulsed field. Associated instrumentation is positioned on the balcony above the solenoid magnet.

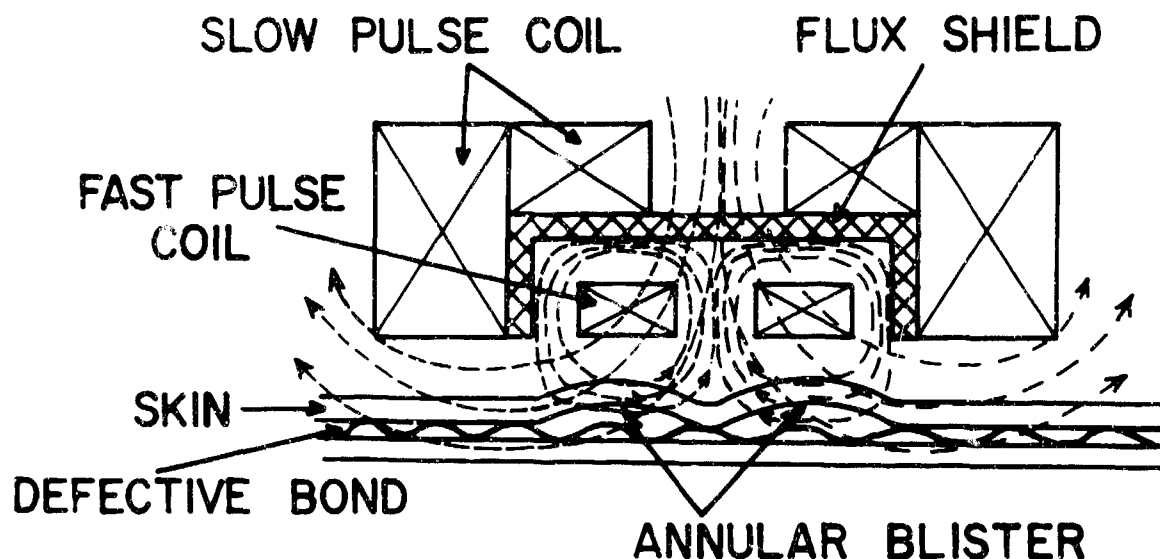


Figure 2. Schematic geometry of an electromagnetic traction device for a proof-loading machine capable of testing extended panels of bonded aircraft structures.

general physics

ELECTRON STRUCTURE OF TETRAHEDRALLY BONDED SEMICONDUCTORS

The electronic properties of crystals are being utilized in an ever-increasing number of applications. Lasers, solar cells and various transistor devices are but a few examples. Scientists and engineers are more and more forced to seek the understanding of electronic characteristics in order to design hardware. Hence a requirement exists to determine the properties of a large number of different crystals and to be able to explain these properties from theoretical models.

Consequently, the Solid State Physics Research Laboratory's Theoretical Group at ARL, consisting of Dr. R. N. Euwema, Major D. J. Stukel (Ph.D.), and Dr. T. C. Collins, conducts a research program whose goal is to calculate the electronic properties of any tetrahedrally bonded semiconductor from only a knowledge of basic quantum mechanics. All other existing electron-energy band calculations require a large amount of experimental information as input to the theoretical calculation. The results of this study have given satisfactory electron-band structures of a large number of compounds, such as the example of GaAs given here. The only experimental information

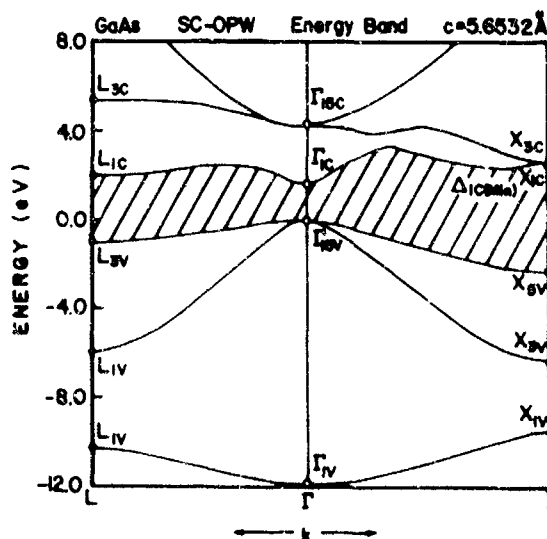


Figure 1. Electronic structure of GaAs.

used was the atom spacing.

The self-consistent orthogonalized plane wave method, where Slater's approximation was made for

the exchange term, was used to obtain the electronic structure of GaAs shown in Figure 1. Three minima were found in the conduction band. The lowest minimum occurs at the $k = 0$ point. When an electric field with enough energy is applied, electrons at the $k = 0$ point can go to the next minimum (L-point

minimum) located at 0.38 eV above the first minimum. This causes oscillations in the conductivity curves, the so-called Gunn effect. The calculated bands also explained photoemission data, hydrostatic pressure data, and reflection data which had been misinterpreted until now.

general physics

MAGNETIC FIELDS FOR INTRAVASCULAR NAVIGATION

Neurosurgery may soon benefit from magnet technology at the AFOSR-sponsored Francis Bitter National Magnet Laboratory at MIT. A magnet system capable of guiding a ferromagnetic-tipped catheter through blood vessels in the brain is under development as a joint project of the Laboratory's Magnet Research and Technology group directed by D. Bruce Montgomery (Ph.D.), and medical researchers William Sweet (M.D.), Lewis Wright (M.D.),

and Shyman Yodh (M.D.) of the Massachusetts General Hospital. A rotatable iron magnet, which has been employed in preliminary experiments with laboratory animals, has indicated the feasibility of this technique, and a more advanced system, which will be required for sophisticated medical applications, has been proposed.

Catheters suitable for introduction into the intracranial vessels are very different from those used

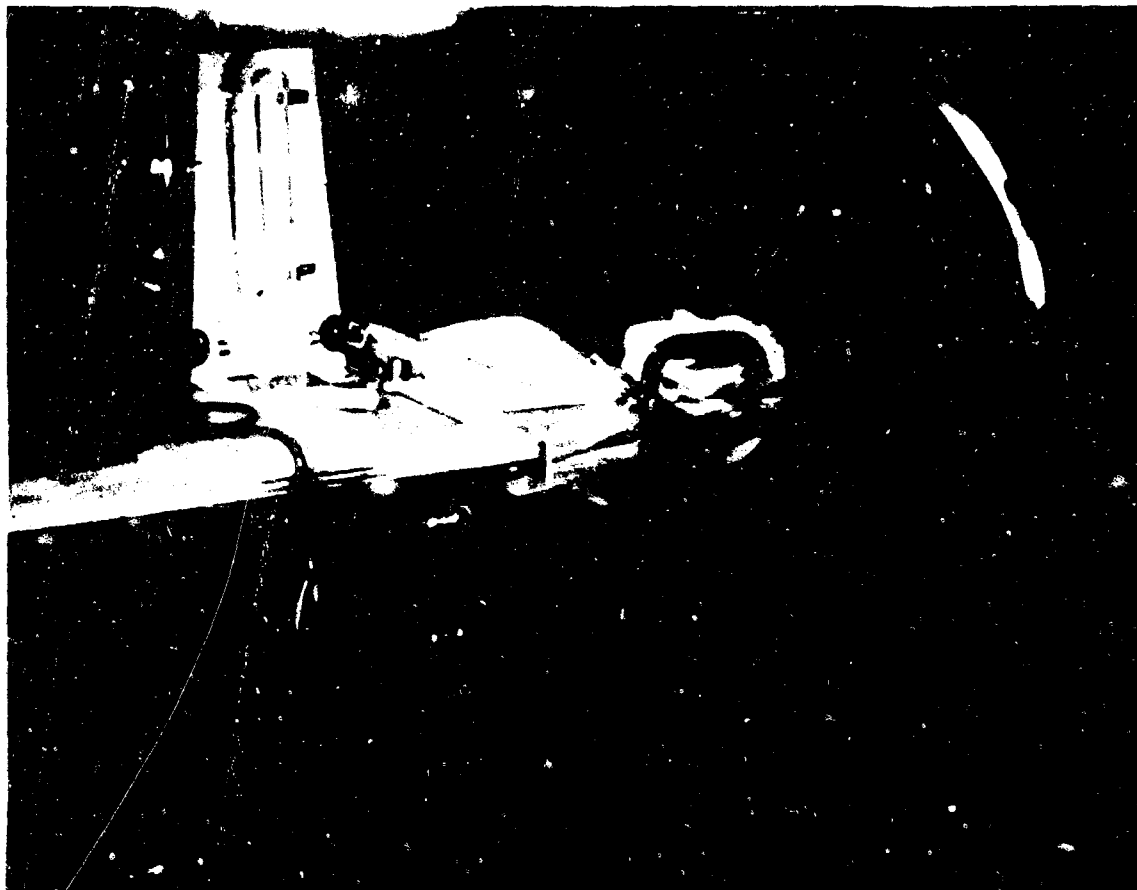


Figure 1. Electromagnet designed to produce a magnetic gradient which could be oriented in different directions around the head of the mannequin shown. The permanent magnet tip on the catheter always points toward the electromagnet pole, and is attracted to it.

in the heart and other areas of the body. They must be extremely soft and flexible, and less than 1 mm in diameter. As such, they can clearly not be pushed forward, but must be pulled and guided from the tip. External magnetic gradients acting on permanent magnet tips offer this possibility. The catheters are introduced through a special 1-mm-diameter needle which punctures the carotid artery in the neck, and are then drawn upward into the vascular tree by properly directing the magnetic gradient.

The electromagnet shown in Figure 1 was built by the Laboratory to produce a magnetic gradient

which could be oriented in different directions. The permanent magnet tip on the catheter always points toward the electromagnet pole, and is attracted to it. The pole is then moved as the tip progresses so that it is always lined up with the blood-vessel direction at any given tip location. Superimposed on the field gradient is an oscillating magnetic field which induces friction-reducing vibrations in the catheter.

To obtain a strong force, a strong field gradient is required. The gradient which can be produced at a distance several inches away from a hand-held permanent magnet is much too small to be useful. Even the

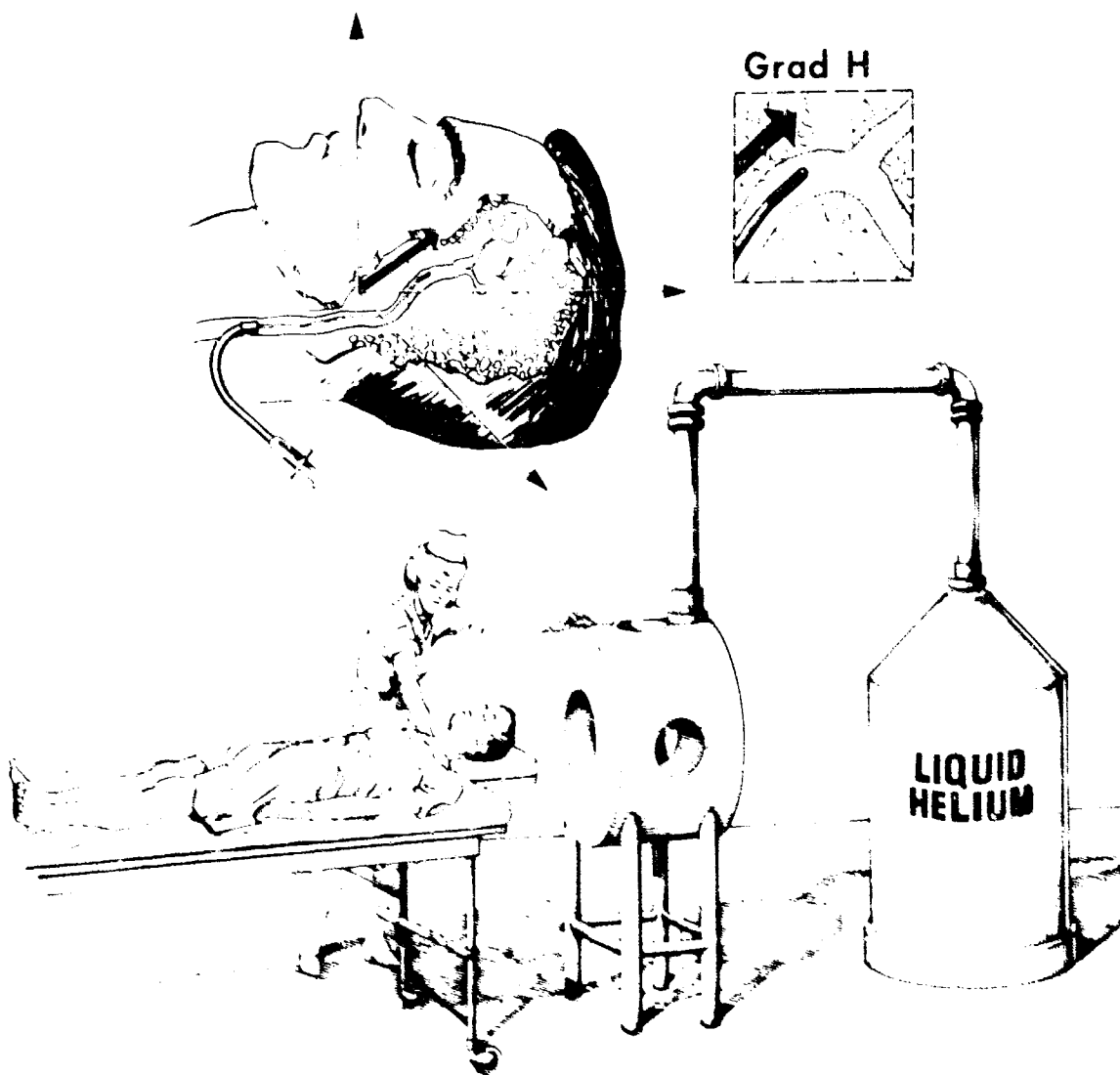


Figure 2. Magnetic guidance system for permanently magnet-tipped catheters, under development for neurosurgery applications by MIT Francis Bitter National Magnet Laboratory and Massachusetts General Hospital. Three orthogonal pairs of superconducting coils can produce a 10^3 G/cm gradient oriented at any location of the tip, thus exerting a properly directed force. Access ports in cryostat allow X-ray monitoring of tip position.

5kW electromagnet of Figure 1 can only produce a 50 Oe/cm gradient at the opposite side of the head, which will exert only 0.15 grams of force on a 0.9-mm-diameter-by-3-mm-long tip. What is needed for sophisticated maneuvering in small passages are the gradients which can be produced by superconducting windings, easily 10 times higher than those the electromagnet can produce.

A superconducting system proposed for neurosurgical use is shown in Figure 2. Inside the cryostat are three sets of orthogonal coil pairs and, by properly proportioning the currents between the sets, a gradient can be produced in any direction in space without actually moving the magnet. The cryostat provides a 25-cm room-temperature access for the head, and 2 orthogonal 15-cm-diameter access holes, and is sufficiently short so that its center can coincide with that of the head without interference with the shoulder area. Liquid helium will be supplied from a permanently connected external storage vessel.

For the first time neurosurgeons see the possi-

bility of introducing catheters, which are simply flexible tubes, into areas of the brain which are otherwise inaccessible except through major surgery. Such guided catheters could be used both in diagnosis and in clinical treatment—for example, for blocking feeder vessels of certain intracranial vascular malformations, or for the local injection of high concentrations of a radio-opaque medium for X-ray diagnosis, or for the injection of chemotherapeutic agents for the treatment of tumors, aneurysms and arteriovenous malformations.

In addition to the catheter project, the Laboratory is engaged in other biomedical applications of magnetic fields including stimulation of the heart by pulsed magnetic fields and measurement of the weak magnetic fields associated with heart and brain electrical activity to produce magnetocardiograms and magnetoencephalograms, without the need to paste on the wired electrodes for electrocardiograms and electroencephalograms.

general physics

INDUCED ELECTRON-EMISSION SPECTROSCOPY

When small amounts of certain chemical elements are incorporated in suitable crystals, they may dominate the properties of this crystal, i.e., their

electronic-level scheme determines the desirable properties of the material. For example, in ruby the particular levels of the dilute chromium in an Al_2O_3

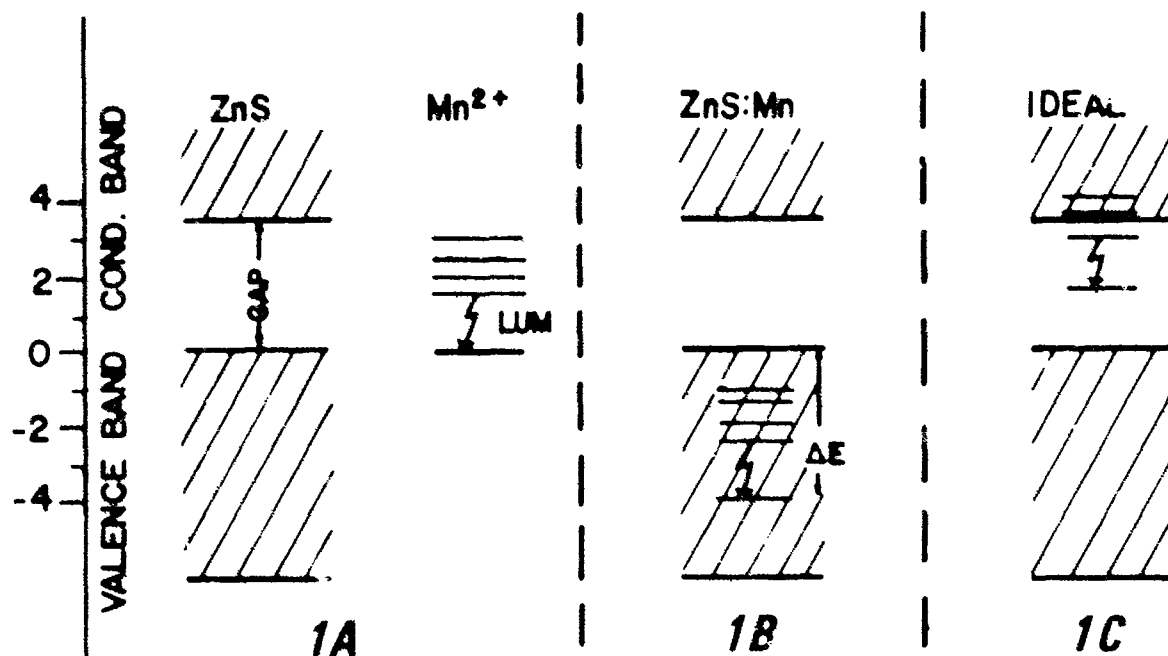


Figure 1a. Energy levels for host lattice and impurity are determined separately by optical spectroscopy on ZnS:Mn .

Figure 1b. Relative position of Mn^{2+} ground state and energy spectrum of host lattice, $\Delta E = 4\text{eV}$, as determined by Varian IEE spectrograph.

Figure 1c. Ideal system: efficient luminescence of impurity center may be pumped by injection.

host lattice cause the lasing transition.

The positions of deep impurity levels relative to the energy levels of the host lattice are known at present only in very few materials. Yet they are very important, because the relative positions may determine whether the impurity ions may be excited easily by electronic interaction with the host lattice. Thus, under suitable conditions, highly efficient luminescence or lasing action may be produced by convenient electronic pumping in contrast to optical pumping.

Recently a new technique, Induced Electron Emission (IEE), has been developed which makes it possible to determine the relative positions of energy levels of the host lattice and impurities. The energy spectra are determined by the photoelectric-emission spectroscopy: monochromatic X rays are absorbed and electrons are emitted from the occupied energy levels. Analysing the energy of the emitted electrons furnishes the absolute locations of the energy levels of the host lattice and the impurity.

Figure 1 illustrates this for ZnS:Mn, a well-known luminescent material. By means of optical absorption and emission spectroscopy, the ZnS gap

and, independently, the level structure of Mn^{2+} relative to the Mn^{2+} ground state (Figure 1a) are determined. But because the region of charge transfer is not optically accessible, one can not determine experimentally the location of the ground state of Mn relative to the top of the valence band of ZnS. Theoretical estimates have put the ground state of Mn as far as six eV below the top of the valence band.

Recently, Dr. D. W. Langer of the Solid State Physics Research Laboratory at ARL decided to attack this problem with the newly established technique of Induced Electron Emission Spectroscopy. Measurements on an instrument of Varian Associates resulted in a determination of the energy difference of the Mn^{2+} ground state and the top of the ZnS valence band, ΔE , which turned out to be four eV (Figure 1b).

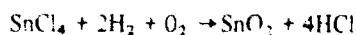
These experiments demonstrated for the first time that energy levels of deep impurities and of host crystals can be determined on the same scale even when charge transfer is not observable. Many more systems should be investigated similarly, with the ultimate aim of finding the system outlined in Figure 1c, where injection-excited luminescence may be expected.

general physics

HIGH-TEMPERATURE SEMICONDUCTOR

Since the early 1950s, the Air Force has supported the development of semiconductor components capable of functioning in amplifiers at elevated temperatures. Results have included silicon transistors which operate at temperatures up to 200°C, gallium-arsenide transistors, and electronic components made of silicon carbide.

Aware of the continuing need for solid-state electronic devices which can operate at higher temperatures, AFOSR is sponsoring the basic research of Professor R. H. Rediker at M.I.T. on the conduction mechanisms of single-crystal tin oxide, SnO_2 . Since tin oxide is physically and chemically stable at elevated temperatures and is a wide-bandgap semiconductor (bandgap of 3.7 electron volts), it is a strong candidate for semiconductor components which could operate at temperatures up to 500°C. In this research a new technique has been developed to grow single crystals of tin oxide. The crystals are grown from the vapor at 1250°C and at reduced pressure using the reaction



The stannic chloride ($SnCl_4$) is obtained from the reaction of tin and chlorine gas at 100°C and reduced pressure



The resistivity of the tin-oxide semiconductor is controlled by adding selected impurities, such as antimony, to the metallic tin.

The crystal-growing apparatus is shown in Figure 1. Note that, by adjusting the relative amount of chlorine flow through the "pure" reactor, which contains only tin, and through the doping reactor, the resistivity of the tin oxide grown can be predetermined, and by varying this relative amount during a run, a desired resistivity profile can be obtained. In the tin oxide that has been made thus far, the conduction has been by electrons—it has been n-type.

A photograph of two typical grown crystals is

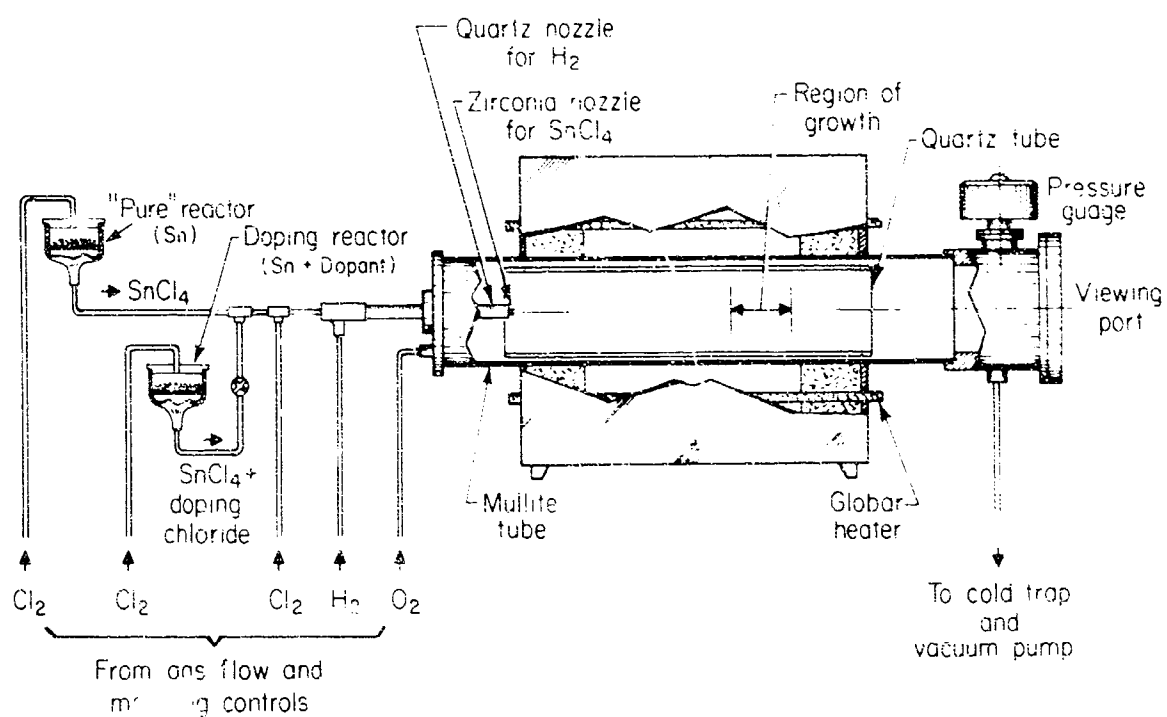


Figure 1. Tin-oxide (SnO_2) crystal-growing system. The drawing is not to scale; the actual mullite tube is 90 cm long, with 5-cm inside diameter.

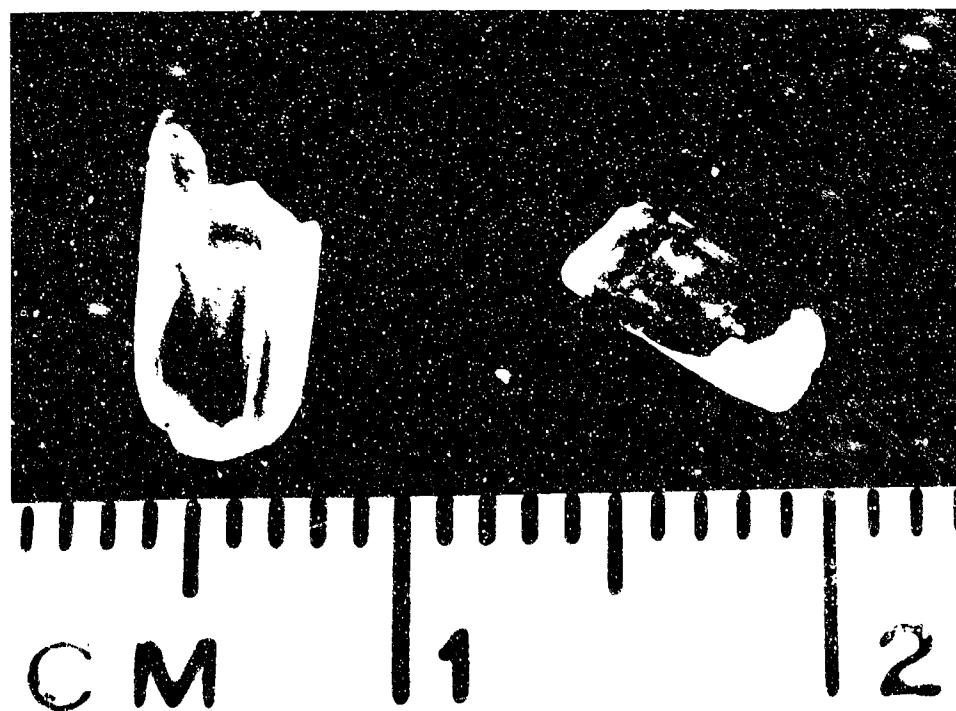


Figure 2. Photograph of 2 typical tin-oxide crystals grown in 40 hours at $1250^\circ C$ and reduced pressure, using the reaction, $SnCl_4 + 2H_2 + O_2 \rightleftharpoons SnO_2 + 4HCl$.

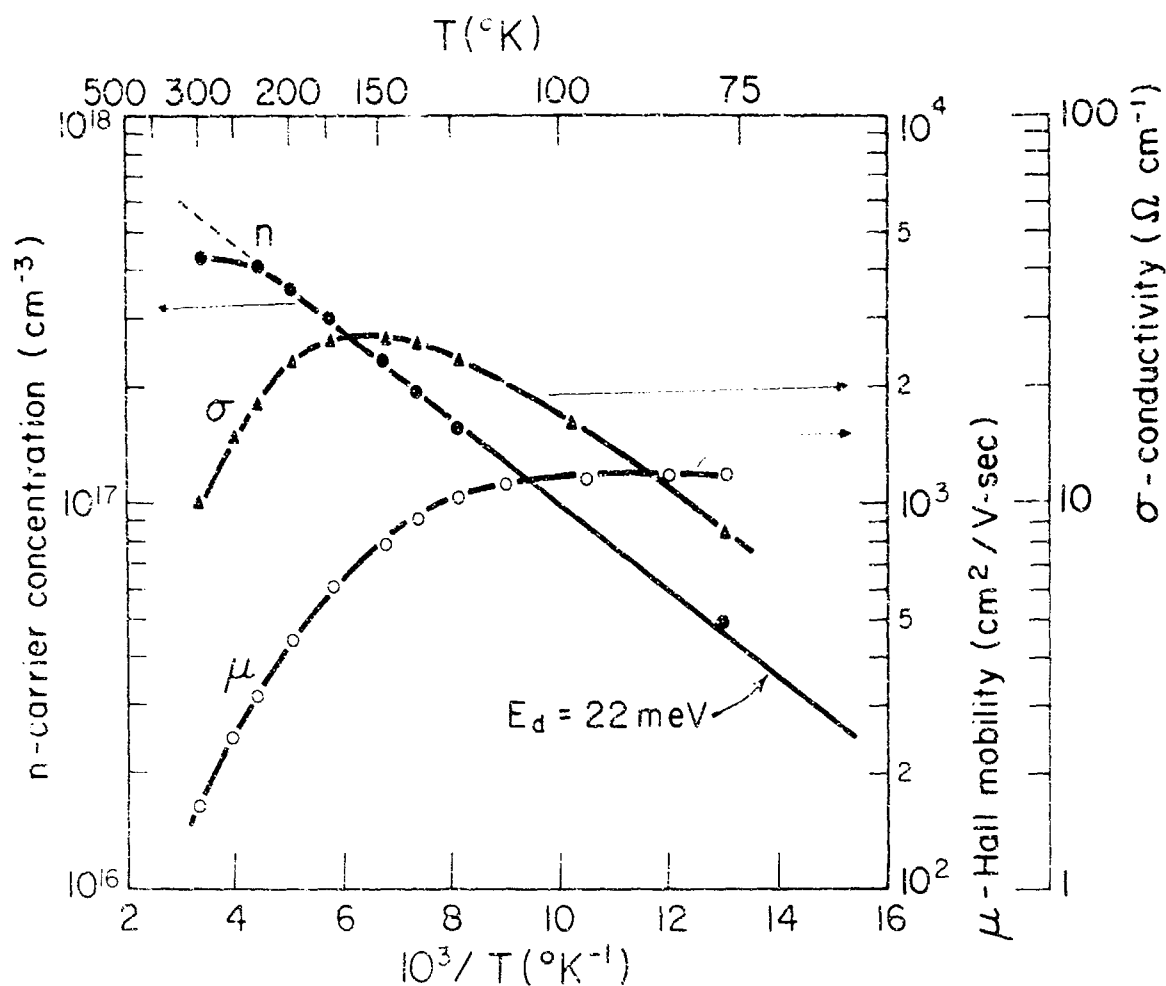


Figure 3. The Hall mobility, resistivity, and conduction electron concentration of an antimony-doped tin-oxide sample measured for temperatures between 77°K and 300°K.

shown in Figure 2. Spectrochemical analyses of such crystals indicate that they are purer than any previously reported. Electrical measurements have yielded a value for the Hall mobility at liquid-nitrogen temperature (77°K) of 1200 cm²/volt sec which is higher than any previously reported, and is consistent with the higher purity. The electrical properties of a crystal doped with antimony to a resistivity of 0.1 ohm-cm are shown as a function of temperature in Figure 3. Plotted are the Hall mobility μ , the resistivity ρ , and the conduction electron concentration n determined from the equation, $n = 1/e\mu\rho$, where e is the electronic charge.

The electrical characteristics in Figure 3 indicate that single-crystal tin-oxide crystals should be usable in semiconductor components which operate at temperatures of 500°C. Although much more basic

research on the conduction mechanism is required before practical tin-oxide high-temperature components can be produced, results thus far suggest a realization of a semiconductor that can operate at red-hot temperatures.

SPIN-LATTICE RELAXATION USING TONE-BURST MODULATION

Much information is available about lattice dynamics through a temperature and frequency-dependence study of spin-lattice relaxation times (T_1) of either native nuclear species, or of unpaired electrons belonging to impurities. (T_1 is the characteristic time associated with the build-up of paramagnetic magnetization, once it has been depleted, usually by a temporary magnetic resonance.) Measurements by Lt David C. Look (formerly of ARL) on Cd^{113} nuclei in CdS were being made by a direct-recovery technique which is good for only T_1 greater than a few seconds. However, in order to measure T_1 for CdO, or for electrons in solids, either

pulsed radio-frequency or microwave techniques (which were not available at ARL) were then considered able to do the job. At this point Lt Look (now Dr. Look with the University of Dayton) and Mr. Donald R. Locker of ARL considered the possibility that a properly constructed modulation scheme for the magnetic field, together with ordinary cw spectroscopy, could produce the same information. Such a scheme is shown in Figure 1. The field is made to stay less than that of resonance for a time greater than $3 T_1$'s. It is then increased and decreased periodically so that the resonance condition is satisfied at equal intervals in a time less than T_1 . The

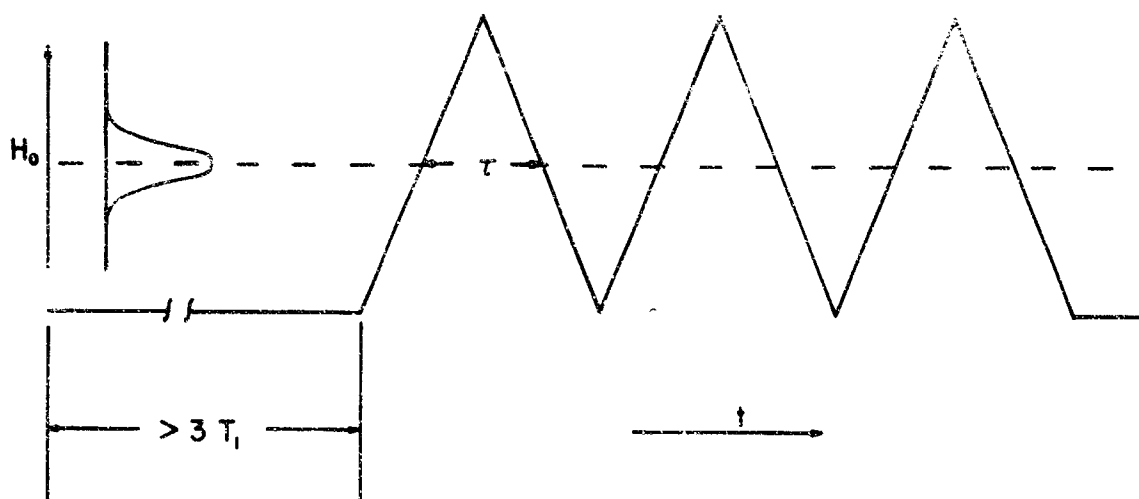


Figure 1. Time-dependence of magnetic field during tone-burst operation.

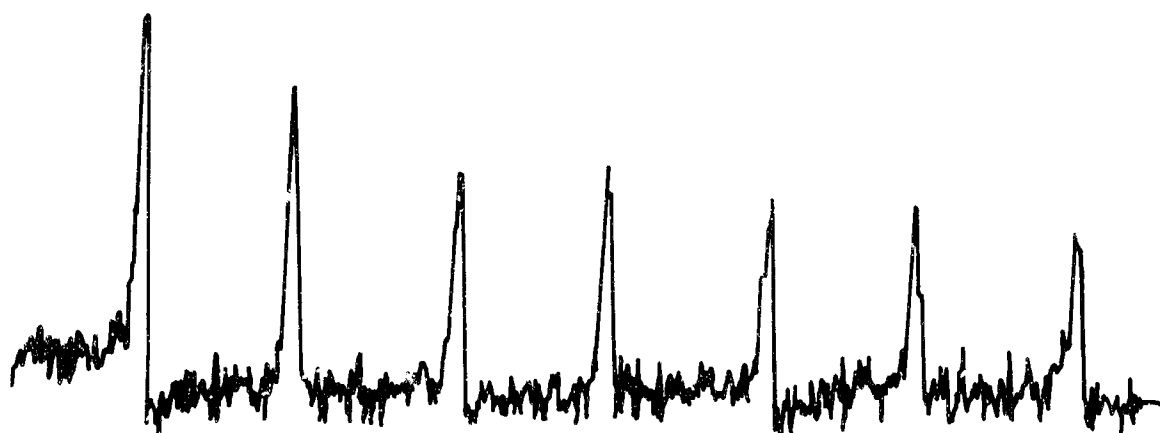


Figure 2. Response of Cd^{113} in CdO to tone-burst field modulation at 14.4 Hz and 14 gauss P-P. Data are taken at 4 MHz rf and at room temperature in 1500 sequences of bursts.

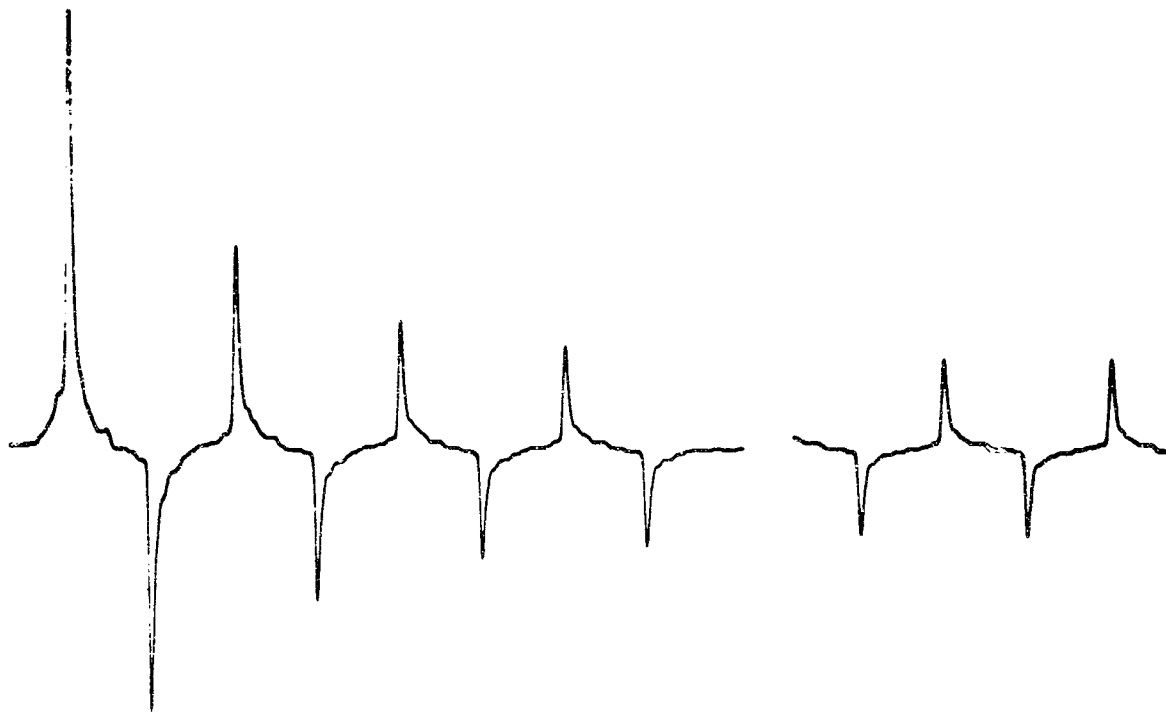


Figure 3. Response of MgO:Cr^{3+} resonance at 4.2°K and 9.6 GHz to tone-burst modulation, $\tau = 0.5$ sec ($f=20$ Hz). Second trace is free-run response.

signal one gets is proportional to the instantaneous magnetization just before a crossing. At the first crossing, the magnetization is at its equilibrium value M_0 , but an amount xM_0 gets used up in crossing resonance. Before the next crossing, the magnetization builds up exponentially, but to a value less than M_0 . This magnetization reduction continues until an equilibrium is reached between recovery and

resonance depletion. The mathematical description for this situation has been worked out for the general case and enables one to calculate T_1 from the sequence of peaks. The technique and assembled low-cost equipment have been very successful for both NMR (Figure 2) and EPR (Figure 3). The equipment is shown in Figure 4.

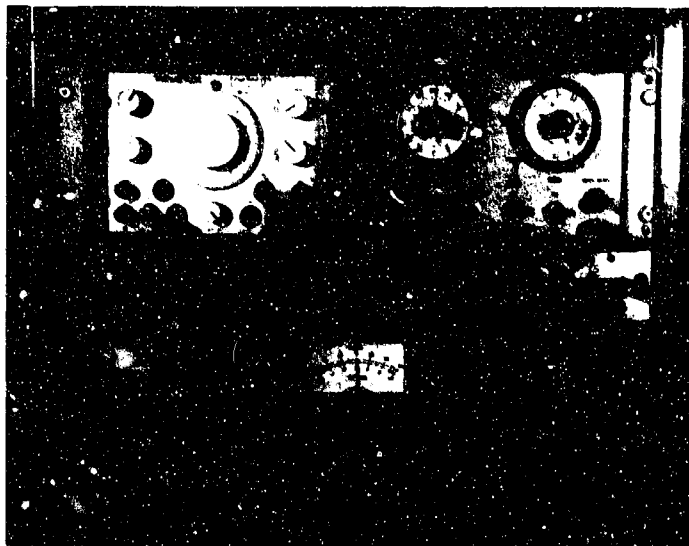


Figure 4. The heart of the apparatus is made up of low-cost commercially available components.

SUPERELASTIC ELECTRON COLLISIONS

Recent instrumentation improvement has permitted research that has both detected and applied an elusive phenomenon, superelastic electron impact. Such an impact is one where an electron gains energy, hence velocity, from a collision with an excited atom or ion in contrast to losing energy, as is the usual case. An experiment in this area was conducted at Yale University under AFOSR contract F44620-69-C-0018 and is reported in the Bibliography (under the same title as above).

Figure 1 is a schematic of the instrument which is cylindrical in form around an axis leading through the clear channel from the filament to the electron collector, EC. Not shown in the schematic are three items: a quartz-glass vacuum envelope, an array of rubidium arc lamps that illuminate the collision chamber, and a solenoid coil that produces a 180-gauss, axial magnetic field which confines the electrons to paths near the axis.

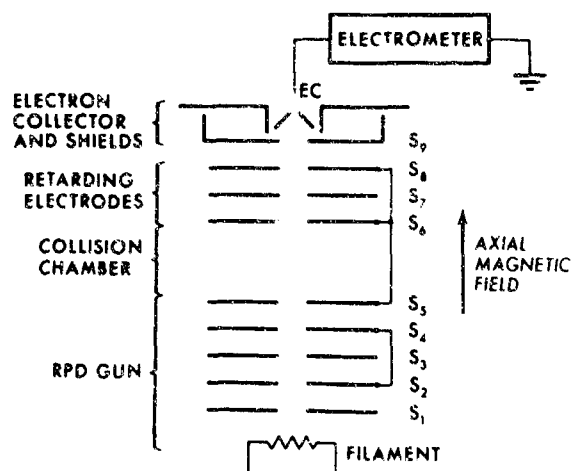


Figure 1. Schematic diagram of the electron gun.

In operation, electrons from the filament and grids S_1 to S_5 emerge in alternate bunches at two similar but slightly different energies. This array is called a retarding potential difference or RPD gun. The collector and electrometer subtract the energy of two bunches, thus giving an equivalent 0.2 electron volt (eV) energy resolution to the detected electron beam. In the collision chamber, rubidium vapor is excited by the arc lamps and transfers part of the energy of the resulting excited state to nitrogen molecules, N_2 . These in turn are traversed by the electron beam. The grids S_6 to S_9 suppress the electrons which have lost energy or stayed constant in

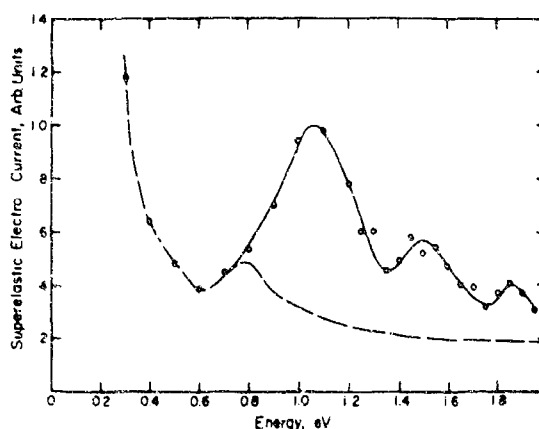


Figure 2. Superelastic current from N_2 plus Rb, solid curve, and from Rb alone, dashed curve.

energy, thus allowing only those which have gained energy, i.e., suffered a superelastic collision, to reach the electron collector. An additional feature of this set of grids is that the potentials can be varied further to determine the number of superelastic electrons in small energy steps. The results are shown in Figure 2. Also included is the smaller and broader curve for superelastic electrons arising from the rubidium ions.

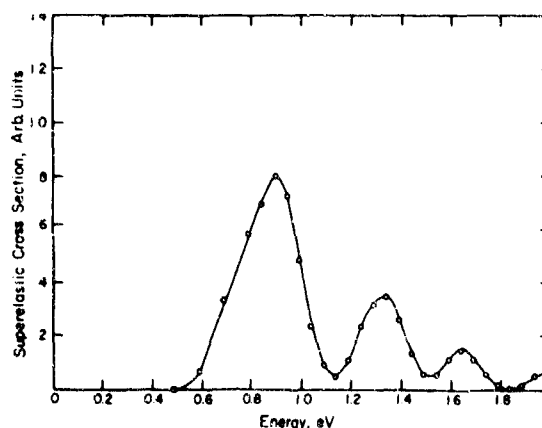


Figure 3. Superelastic cross sections, relative, for $V=5 \rightarrow V=0$ in N_2 .

The latter curve is obtained, obviously, by omitting the nitrogen from the collision chamber. The difference curve showing the energy dependence of the superelastic cross section for nitrogen in the transition from the fifth vibrational state to the ground or zero vibrational state is given in Figure 3. The

principal merit of this experiment is the high resolution over the one-half to two eV range of energies.

Calling this experiment an "application" of superelastic electron scattering arises as follows. The arc lamp excites the Rb atoms into a pair of long-lived energy states at 1.57 to 1.59 eV. The process of transferring this energy to a second species, nitrogen in this case, is called quenching as it returns the metallic atom to the ground state. This is important in many electronic, plasma, and gas-laser

systems. The new knowledge here is experimental proof that nitrogen quenching is about 10 times as efficient for alkali metals including rubidium as for other combinations found to date. A further finding is that vibrational levels of the quenching gas ($v = 5$) can be more than 80% of the energy of the Rb metastable state and thus are very efficient in de-energizing unwanted metastable states. Data of this type also contribute to an understanding of energy conversion in upper-atmospheric and solar-corona processes.

general physics

ARGON PLASMA SPECTROSCOPY

Optical studies of high-temperature argon in electrical-arc discharges have been conducted by Dr. Wolfgang G. Braur, and his associates in the Plasma Physics Research Laboratory, ARL, to gain a better understanding of basic atomic emission and absorption processes. Radiative emission and absorption are fundamental to high-temperature heat transfer, high-intensity light sources, and the interpretation of astrophysical observations.

The value of spectroscopic methods for plasma diagnostics has been pointed out by many authors, but the correct and accurate interpretation of the measurements depends on the establishment of a reliable system of atomic parameters. Measurements, with radiation sources operated under conditions which permit the application of certain theoretical relations, provide atomic constants such as energy levels, transition probabilities, and line-broadening parameters. In very few spectroscopic sources do conditions prevail which allow conclusions based on the validity of the Boltzmann distribution formula or Kirchhoff's law. The ideal source for quantitative spectroscopic investigations would be a plasma in local thermodynamic equilibrium (LTE) but, with laboratory-produced plasmas, deviations from LTE must be tolerated, assessed, and allowed for in the evaluation of the data, if possible.

Atomic parameters of argon have been obtained from measurements with electrical-arc discharges which have been evaluated with the assumption of LTE. Olsen (see Reference 1 in Bibliography) used a free-burning arc between a pointed tungsten cathode

and a flat copper anode and, in a detailed study, found incompatibilities in the results which he traced to deviations from LTE in his arc. Braun and his co-workers undertook the study of this complex, intriguing problem to determine if a quantitative assessment of deviations from LTE could be made. A vortex-stabilized arc and a free-burning arc were probed spectroscopically in emission and absorption by the tracking mirror method (Reference 2).

The result of an experiment in the vicinity of the argon I line at 7637 Å is presented in Figure 1. The height of the surface, drawn by a computer program, represents the absorption coefficient as a function of wavelength and the distance from the center of the arc. True values of the absorption coefficient cannot be expected in those zones of the profile where the spectral resolution of the monochromator used approaches the width of the absorption line, nor in those wavelength regions where the transmission factor approaches unity, i.e., where the arc plasma is optically thin. Aside from the variations in width and the shift of the absorption line in the core of the arc, the surface discloses a narrow absorption ring at a radius of about 5.5mm. Simultaneously obtained profiles of the emission coefficient vanish for radii greater than 3.5mm which indicates an overpopulation of atoms in the lower, metastable state of the observed transition in the ring. Similar rings were obtained at the wavelengths of other transitions to the same level, pointing to a sheath of metastable atoms around the arc. This reveals a deviation from LTE; the distance a particle or photon travels between equilibrating collisions spans too large a change in

electron density and temperature, despite the high pressure in the discharge. But allowance for the measured self-absorption in the evaluation of the intensity profiles restores the validity of the transition probabilities obtained with this arc. An absorbing sheath which is caused by the ultraviolet

resonance radiation emitted by the core of the arc has been detected also. This again is evidence that the mean free path of the photons is larger than the core of the arc; but, in principle, this is compatible with the concept of LTE.

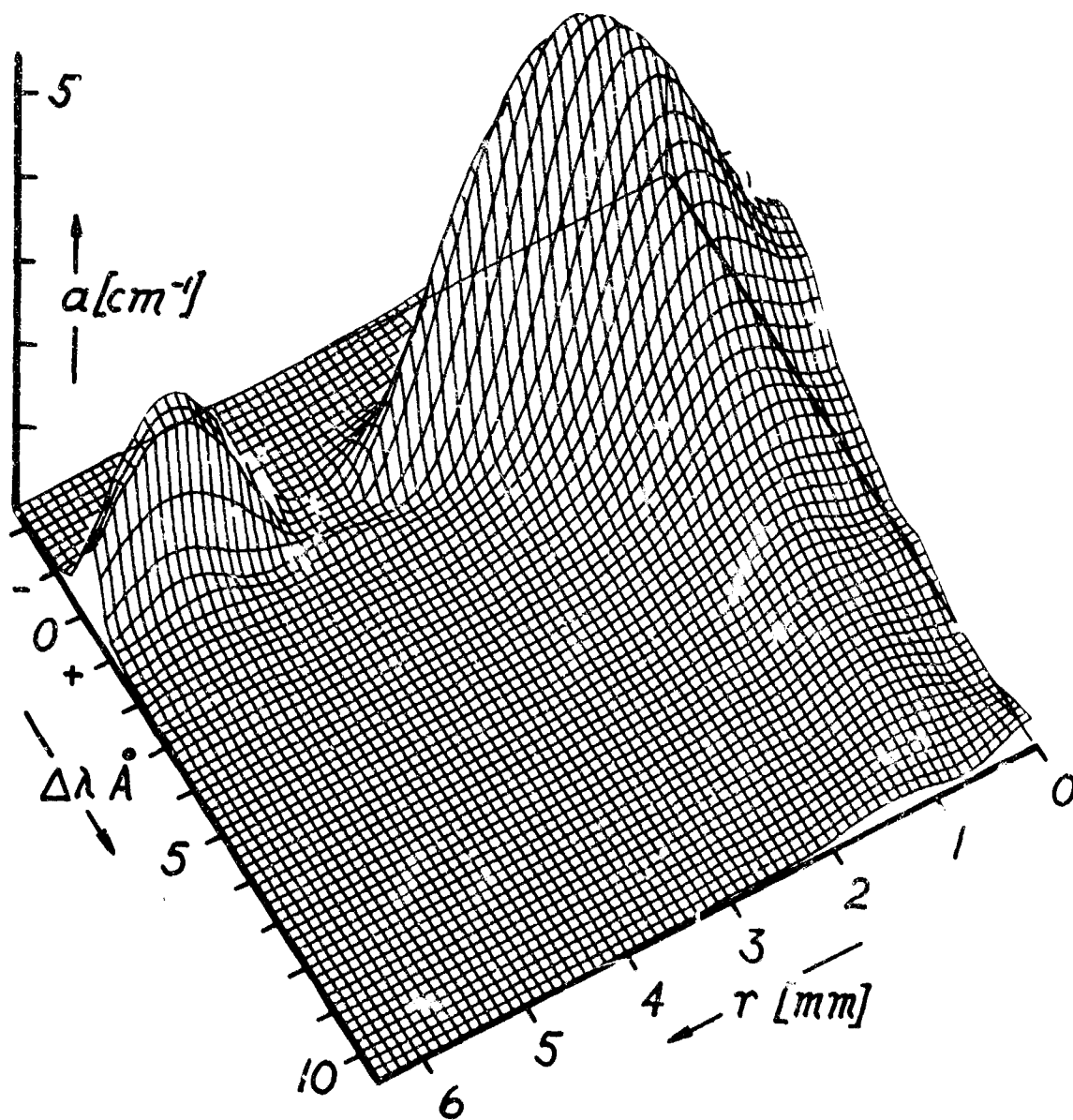


Figure 1. Absorption coefficient $a(\lambda, r)$ in the cross section of an argon arc at 7637\AA and at a pressure of 2 atmospheres.

HIGH-GRADIENT, HIGH-INTENSITY FIELDS FOR ORE SEPARATION

The force which can be exerted magnetically on a magnetic particle is proportional to three quantities: the gradient of the applied magnetic field, the size of the particle, and the magnetization of the particle (whether permanent or induced by the applied field). In cases involving relatively large particles which are highly ferromagnetic, a force adequate for separation can be achieved by simple means. Magnetic separators are commonly used to remove such particles from a nonmagnetic medium in the form of a wet slurry or suspension, a fluidized (gas-supported) bed, or a simple dry aggregate. However, there are many cases of considerable interest in which magnetic separation has never been possible on an industrial scale, due primarily to the very rudimentary state-of-the-art. Such cases involve particles which are either too small in relation to commonly achievable gradients, or too difficult to magnetize in relation to commonly achievable field intensities. There may also be more subtle difficulties.

The Francis Bitter National Magnet Laboratory has responded to several requests for assistance in solving magnetic separation problems. Even this casual and purely informal contact with the industry has led to at least one new industrial process. There is no question but that a great deal of economic and even strategic value can be achieved by applying more sophisticated methods of magnet design to magnetic separation. Ironical though it may seem, it is likely that superconducting magnets, in their present state of development, are ready to make a substantial contribution in the one area which has never been mentioned in any of the numerous speculations concerning superconducting applications: ore separation.

The most successful innovation in magnetic separation has been in the purification of kaolin for use in paper coating. This involves the removal of particles which are very small (colloidal and subcolloidal), very weakly magnetic (they only contain trace amounts of iron in the form of stain), and which must be removed to a very complete degree for the process to be of any value. Fortunately, these difficulties are offset by a very substantial advantage:

the cost of the separation need not be borne by the very small fraction of magnetic material which is removed, but may be allocated to the bulk of the feed which is thereby purified. Thus, a cost figure which is prohibitive in dollars per gram removed becomes very attractive in dollars per ton purified. Dr. Henry Kolm of MIT succeeded in developing a magnetic separator capable of outperforming the chemical separation process used previously, and even utilizing grades of kaolin not previously amenable to economic purification. The device makes use of magnetized stainless steel wool in a large volume of high field gradient, and a magnetizing field somewhat higher than can be achieved in commonly used industrial separators. The first production capacity separator has been installed in a Georgia clay mine.

A second application being pursued informally for some time involves the removal of nonsulfide molybdenum and tungsten from what is now the tailing flow from the Climax Molybdenum Company's operation. Only molybdenum sulfide can be recovered economically by present means. The loss of nonsulfide molybdenum represents an estimated \$20,000 per day.

Tests so far have indicated that the method applied to kaolin will work in principle, but fails to achieve practical through-put rates. It also requires the prior removal of coarse components. Results obtained so far suggest another promising approach: a continuous flow process using a quadrupole gradient.

Another application under study at present involves pollution control in the steel industry. The problem involves the removal of small amounts of finely divided steel from large volumes of process water to permit its re-use in rolling mills, thus precluding its discharge into rivers and lakes. A similar problem is the removal of slag particles from the flue gases of blast furnaces. Although scrubbers are capable of accomplishing the required cleanup, the same pollution then appears in the discharge water from the scrubbers. Preliminary tests indicate that magnetic separation is likely to solve both problems.

nuclear physics

HARD X-RAY PULSAR

Since the discovery of the first pulsar was reported, in February 1968, (see Reference 1 in Bibliography) more than 35 of these rapidly pulsating radio sources in space have been revealed. The goal of this flurry of experimental activity has been to discover the nature of the sources and the mechanism of production underlying the pulsed radiation. Present theories hold that pulsars are associated with rotating neutron stars, stars that have exploded their gaseous outer shells into space and now remain as gravitationally collapsed concentrated cores of nuclear matter having a density of about a billion tons per cubic inch. These stars are assumed to have attached to them extremely strong magnetic fields whose drag should gradually tend to slow down the rate of rotation.

One of the most interesting known pulsars is one associated with the Crab Nebula, the optical remnant of a known supernova explosion which was observed by the Chinese on July 4, 1054. This pulsar, designated NP 0532, was discovered in late 1968 (2) and pulsates the most rapidly, doing so at the rate of 30 times per second. (3) Since its discovery, pulsating

optical (4) and soft X-ray (5, 6) signals, having the same macroscopic structure, have been associated with it.

Recently, still another feature of NP 0532 has been revealed by a detailed computer analysis of data recorded nearly two years ago in a balloon-borne experiment to investigate the hard X-ray emissions from the Crab Nebula. This work was done by Dr. R. C. Haymes at Rice University, under an AFOSR contract. His analyses (7) have revealed that NP 0532 emits pulses in yet another region of the electromagnetic spectrum, the hard X-ray. These signals also retain the same double-pulse structural features of the radio pulse. The rate of change of the period between pulses obtained from the Rice data, 56.51 ± 0.02 ns day⁻¹, correlates with the radio and optical data, and is consistent with a neutron-star source whose rotation rate is decreasing.

The identification and investigation of neutron stars through the observation of pulsars could open up a whole new realm concerned with the astrophysical exploration of extremely dense matter as well as of very-high magnetic and gravitational fields.

nuclear physics

THE SHELL MODEL IN MEDIUM MASS NUCLEI

Theoretical models are constructed for the purpose of representing a huge mass of experimentally observed phenomena with a single compact formalism. In recent years much new experimental data has been amassed concerning the structural properties of atomic nuclei. These data come from laboratories with reactors or accelerator facilities such as the ICT-tandem and Van de Graaff accelerators at ARI's General Physics Research Laboratory. The new data provide more guidance, more tests, and more incentive for theoretical models of the nucleus.

One project in this Laboratory concerns the properties of nuclei in the mass range from atomic mass 28 to 40 or 50, and the application of the nuclear shell models to these nuclei. This mass range will serve as a boundary for the following discussion.

In thinking about a model of the nucleus, one may use pictures such as that of a tiny solar system. But the nucleus is on the order of 10^{25} times smaller than a solar system; nuclear particles travel across the nucleus 10^{27} times faster than the planets across a solar system, and are bound by a force 10^{38} times

stronger. The vast differences in size, time, and force tell why we are not surprised that the laws which govern a solar system and other macroscopic bodies do not work for a nucleus. The nucleus is too small to interact with visible light and, because of that, we shall never see a direct visual representation of what it "looks like." The strength of the nuclear force enables the nucleus to store the incredible quantities of energy which are released from the stars and from nuclear reactions and explosions. But the precise nature of that force is not yet known.

The success of all of today's nuclear models rests largely on the success of the nuclear shell model. In turn, the success of the nuclear shell model rests largely on the validity of our assuming that the nucleus can be described as a few nucleons traveling in an average potential produced by an inert core consisting of the remaining nucleons. Since the nucleus is a many-body system, the shell model begins with a set of exact solutions for noninteracting nucleons. One then introduces a residual nucleon interaction as a perturbation to obtain a corrected set

of wave functions. The form for the residual interaction is, therefore, of central importance.

Three methods have been used with great success to arrive at a correct residual interaction: (1) one method parameterizes the residual interaction by a finite set of matrix elements which are determined by a numerical fit to experimental data; (2) a theoretical treatment of the two-nucleon interaction can be used to obtain a theoretical form for the residual interaction; (3) a modified surface delta function with empirically determined strength is now being widely used. This last form of residual interaction is highly useful because of its computational simplicity and, at the same time, it provides a good approximation to the residual interaction, as it is currently understood. Specifically, we now know that this interaction occurs mainly on the nuclear surface, and is short-range, and saturated; this gives rise to nucleon pairing.

One result of this work is that the nuclear properties are not very sensitive to the precise details of the residual two-nucleon interaction. Current methods for treating the interactions produce good results. A second problem now appears to be dominant in limiting the accuracy of the model. This problem arises because the actual solutions are linear combinations of the functions of a Hilbert space of infinite dimensions defined by the unperturbed wave functions. In principle, the model would require the diagonalization of infinitely large matrices. For practical reasons, this cannot be done, so one is always forced to use a finite basis, the size of which is limited by one's capacity for numerical computations. In practice, the addition of just a few more basis-states can blow the problem up from a half-hour hand calculation to a computation outside the capability of even the largest existing electronic computer. It now appears that some nuclear states and some nuclear properties may be quite dependent on the choice and number of basis wave functions. An investigation of this question can be conducted only after the development of solutions using very exten-

sive bases. Computer codes for this have come into existence during the last year and should soon furnish much information about this problem.

One of the major projects in this Laboratory recently has been the search and discovery of a number of nuclear excited states in several medium-mass nuclei which have properties characteristic of simple one-, two-, or three-nucleon configurations. (see References 1 and 2 in Bibliography) Research in this area has been led by Drs. G. I. Harris, J. C. Manthuruthil, C. P. Poirier and D. D. Watson, with much active and helpful participation from all of the Laboratory staff. These excited states can be explained by tractable forms of the nuclear shell model. A knowledge of the properties of these excited states plays a guiding role in the development of the theory. Furthermore, the understanding of the few outermost nucleons of a nucleus largely determines how the nucleus will behave in any nuclear reaction, much as the valence electrons of an atom determine its chemical properties and behaviour. Thus, we feel there is much to be learned about nuclear behaviour by understanding the behavior of a nucleus' outermost nucleons. For this the shell model holds some real promise. (Reference 3 in Bibliography) A program to perform such calculations and a comparison with experiment has just been undertaken in this Laboratory by Drs. D. D. Watson and G. I. Harris.

In principle, the shell model could be extended to calculate all nuclear properties in complete detail if one just had a big-enough computer. It could well turn out, however, that this would lead to the description of a relatively compact set of experimentally observed phenomena with a huge mass of theoretical formalism. This is exactly contrary to the criterion for a good theory presented at the beginning of this article. Thus, new thinking and additional breakthroughs are still required before a completely satisfactory theory of the detailed nuclear motions is available.

nuclear physics

DUALITY DIAGRAMS

Since a conceptual breakthrough necessarily precedes a significant technological breakthrough, it is of obvious interest to the Air Force to foster some research aimed at providing insight into the fundamental nature of matter and energy. One of the important concepts describing the interactions between particles is the concept of exchange. In a two-body reaction, something is always transferred from one particle to another. It may be only momentum, as in an elastic reaction, or it may be any

intrinsic quantum number. We generally think of this transfer as being accomplished by the exchange of a suitable particle between the two partners in the reaction. The exchanged particle or particles, carry over the transferred quantities. The coulomb interaction is, for instance, described by the exchange of photons or light quanta.

In particle physics the situation at low energies, where we find well-defined resonances in the interaction cross sections, is somewhat similar to that

found in nuclear physics. The resonances are interpreted to mean that the incoming particles in the reaction combine to form a well-defined but short-lived intermediate particle which decays into the outgoing particles. At high energies, however, when strongly interacting particles meet, they may exchange a vast number of particles or even families of particles. The Regge-pole model, which was developed from analogy with potential scattering, remains the most successful attempt to understand the behavior of cross sections and the exchange of quantum numbers at high energies. The scattering of particles is described by means of a scattering amplitude $A(s,t)$ which is a function of the energy (s) and the momentum transfer (t) occurring in the reaction. The Regge model connects the s -channel asymptotic behavior (i.e., the scattering at high energies) with the t -channel resonances (i.e., the exchange of well-defined particles such as those seen in low-energy resonances).

One of the most significant recent developments has been the recognition of duality between the resonance production picture and the Regge pole picture. Previously theorists were in the aesthetically displeasing position of having an interpretation which was good at high energies but bad at low energies, and another interpretation which was bad at high energies but good at low energies. During

the past year it has become obvious that each picture contains the other. This duality has been extensively used to determine Regge parameters from low- and intermediate-energy reactions and to use Regge behavior to determine the approximate as well as the average location of resonances.

Earlier this year Dr. Haim Harari (Reference 1 in Bibliography) of the Weizmann Institute of Science and Dr. Jonathan Rosner (2) of Tel Aviv University independently proposed a simple type of diagram which exhibits the duality principle in a striking way. Drs. Harari and Rosner are both supported by AFOSR. The diagrams avoided the underlying redundancy in the usual Regge descriptions, and enabled them to readily reproduce a large number of known predictions of the duality picture, to understand the reason for its apparent failure in baryon-antibaryon scattering, and to derive a large number of new predictions.

In conclusion, to quote Professor Sergio Fubini (3) of the University of Torino, also an AFOSR grantee, "...strong-interaction physics has greatly improved from the naive Reggeology of the early sixties. The possibility is indeed open that the new and exciting ideas proposed in the last few years could open the way to a real understanding of many of the problems of elementary-particle physics."

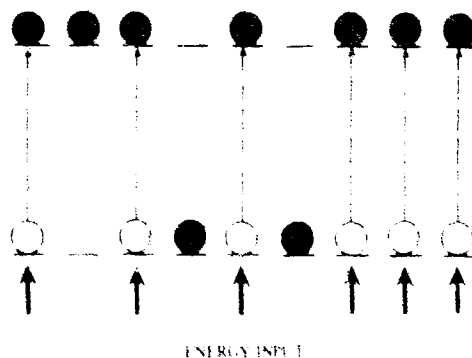
chemistry

THE CHEMICAL LASER—PROGRESS AND PURPOSE

Both the science and technology of lasers have made enormous advance in recent years. The paragraphs to follow will trace the recent progress of the chemical laser, a special type which was first discovered in the laboratory of Professor George C. Pimentel, University of California, under sponsorship by the Directorate of Chemical Sciences, Air Force Office of Scientific Research.

Whether solid, liquid, or gas, the laser emits monochromatic, directional coherent, and intense radiation following an inversion in the normal population of energy states. This inversion, i.e., occupation of higher-energy states than the most stable, requires an input of energy (or "pumping"). This situation is given schematically below:

Light photons of appropriate energy (equal to the difference between the levels) can stimulate relaxation to the lower-energy state, again with the additional emission of photons of the very same energy (wavelength). This is the basis of laser action and the origin of the word (the acronym from light



amplification by stimulated emission of radiation). Taking advantage of vibrational/rotational energy states, a chemical reaction can lead to products of higher energy than those most stable. This sort of energy inversion can lead to laser emission in the infrared. Thus, "chemical activation" is the basis of the chemical laser.

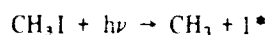
The first "chemical" laser, actually a photo-

dissociation laser, was reported by Professor Pimentel in 1964, based on research by his student, Jerome V. Kasper. Laser action was based on the photolysis of methyl iodide. Kasper also discovered the first true chemical laser (without the quotation marks). This was an "explosion laser" based on the reaction of hydrogen and chlorine. Two other true chemical lasers that have been reported by Pimentel are the abstraction (1967) and the elimination (1968) lasers. Examples of all of these are given in the following table.

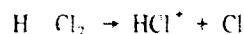
TABLE

Photodissociation and Chemical Lasers
(discovered by G. C. Pimentel and co-workers)

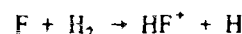
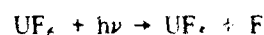
Photodissociation (emitter is I*)



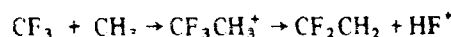
Explosion (emitter is HCl)



Abstraction (emitter is HF)



Elimination (emitter is HF)



In the analysis of the laser emission, the precise changes in vibrational/rotational levels responsible for emission can be identified. It is possible also to gain information about the population density of various excited states produced by the basic reaction (from observed gains in corresponding signal emissions). The chemical laser, then, is an important tool for reaction kinetics. According to Prof. Pimentel, "a chemical laser under control is a poor man's molecular beam."

The future is expected to provide more detailed information concerning basic chemical events which are the key to the laser operation. The ultimate result will be advances in the fundamental understanding of the kinetics of chemical processes.

chemistry

DEVELOPMENT OF A HIGH-EFFICIENCY NEGATIVE ION SOURCE FOR MASS SPECTROMETERS

Ionic reactions represent a significant mechanism for chemical conversion in many high-energy environments, including high-temperature flames, plasmas, discharges, and systems exposed to the flux of nuclear radiation or short-wavelength light. These reactions are therefore an important aspect of the space environment and of atmospheric phenomena. The direct study of these reactions in such high-energy environments, however, is usually not possible at present. Therefore, the most convenient method for detailed investigation of such ionic processes is by laboratory experiments using mass-spectrometric techniques. Most work in this field has been confined to the chemistry of positive ions; conventional mass-spectrographic ion sources do not produce negative ions in sufficient abundance to permit definitive experimentation.

Recently, Dr. T. O. Tiernan of ARL's Chemistry Research Laboratory invented a new ion source and operational mode which yield relatively intense beams of negative ions (Figure 1). Under optimum operating conditions, negative ion currents of the order of microamps can be obtained from this source.

Thus, utilization of this source permits the mass-spectrometric investigation of a wide variety of negative ion reactions. Many of these processes could not be examined previously owing to the extremely low intensities of the negative reactants and product ions obtained with more conventional sources.

It is well known that the most efficient process for producing negative ions by electron impact on neutral species is resonance electron capture, a process which is frequently dissociative. As the name implies, this process is extremely sensitive to the energy of the impacting electrons, and the capture cross section usually exhibits a maximum in the region from 0.1 eV to about 10 eV, depending on the molecule which is ionized. Unfortunately, a conventionally operated ion source, designed to yield impacting electrons with energy at 10 eV or lower, yields very low intensities of negative ions. This is due in part to the fact that it is difficult to produce well-collimated electron beams with these low energies. Moreover, 10 eV electrons can be stopped almost completely in a relatively short distance by many gases at pressures of a few microns in the ion

source. Thus, at such electron energies, many of the negative ions will be formed in the source in a region unfavorable for efficient extraction.

Recent experiments in our Laboratory have revealed a quite different mode of source operation which yields large negative-ion intensities—in many cases currents of microamp magnitude. Briefly, the operating parameters are: (1) a rather-high impacting electron energy of 100-200 eV; (2) the electron trap or anode closely accessible to the ionization region; (3) high anode currents; and (4) the anode operated at source potential.

Solid state data on the energy distribution of

secondary electrons from metal surfaces have shown that, under the indicated conditions, large intensities of secondaries would be emitted from the anode with energies in precisely the region appropriate for electron capture to occur. The specified mode of operation resulted in approximately a thousandfold increase in negative-ion production over that obtainable from more conventional ion sources. This significant development has already resulted in the capability to examine a wide variety of negative-ion reactions which could not previously be adequately studied. The new ion-source design is described fully in a forthcoming publication in the *Review of Scientific Instruments*.

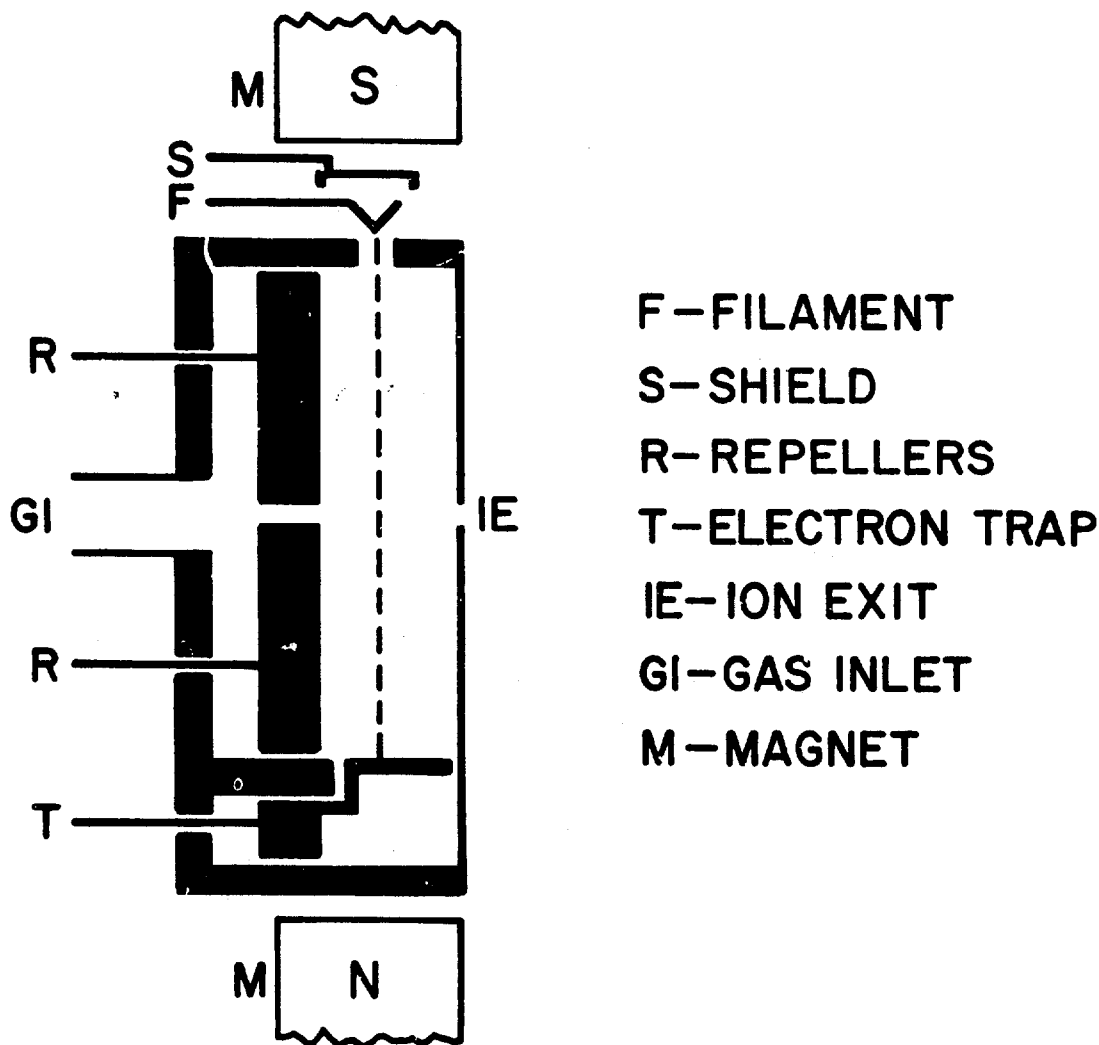


Figure 1. High-efficiency negative ion source for a mass spectrometer. Electrons emitted from a heated filament, F, are accelerated to an energy of about 100 eV, which is too high for the efficient direct production of negative ions. These electrons traverse the source region and impinge on the electron trap, T, which is maintained at the same potential as the source. Secondary electrons of a lower-energy level are then ejected from the trap surface back into the source chamber where they collide with gas molecules. These lower-energy electrons are readily captured by molecules, resulting in negative ion formation. The repeller, R, creates a repulsive field which then accelerates the negative ions out of the source and into the mass spectrometer, where analysis occurs.

ELECTRON-BEAM INTERACTIONS ON SURFACES

There has long been a need to determine the presence and amounts of trace impurities on surfaces in order to assess their role in the many processes of importance in Air Force technology. It is known that small amounts of impurities can greatly influence both the crystallinity and electrical properties of thin films. Thin-film microelectronic devices are widely used in modern Air Force instrumentation, and gains in reliability and performance can be very important. Other areas of technology are also involved, for example, corrosion, lubrication, wear, and catalysis.

Dr. T. W. Haas and his co-workers at the Aerospace Research Laboratories have recently developed a technique for *in situ* detection of surface contaminants. The unique feature of this method is

that it utilizes the same electron optics already used for structural studies by means of low-energy electron diffraction (LEED). Hence, the experimenter can gain both structural and chemical information on the same sample simply by switching the external electronics.

An electron interacting with a solid surface may undergo several kinds of inelastic collisions. Included among the various processes is the Auger transition, a phenomenon which involves the excitation of core electrons to higher-energy levels. When these excited electrons fall back to their ground state, this energy is given off to another electron which is ejected from the solid with a definite energy. Since the various energy levels for a given kind of atom are fairly well known, a qualitative analysis of trace impurities on a

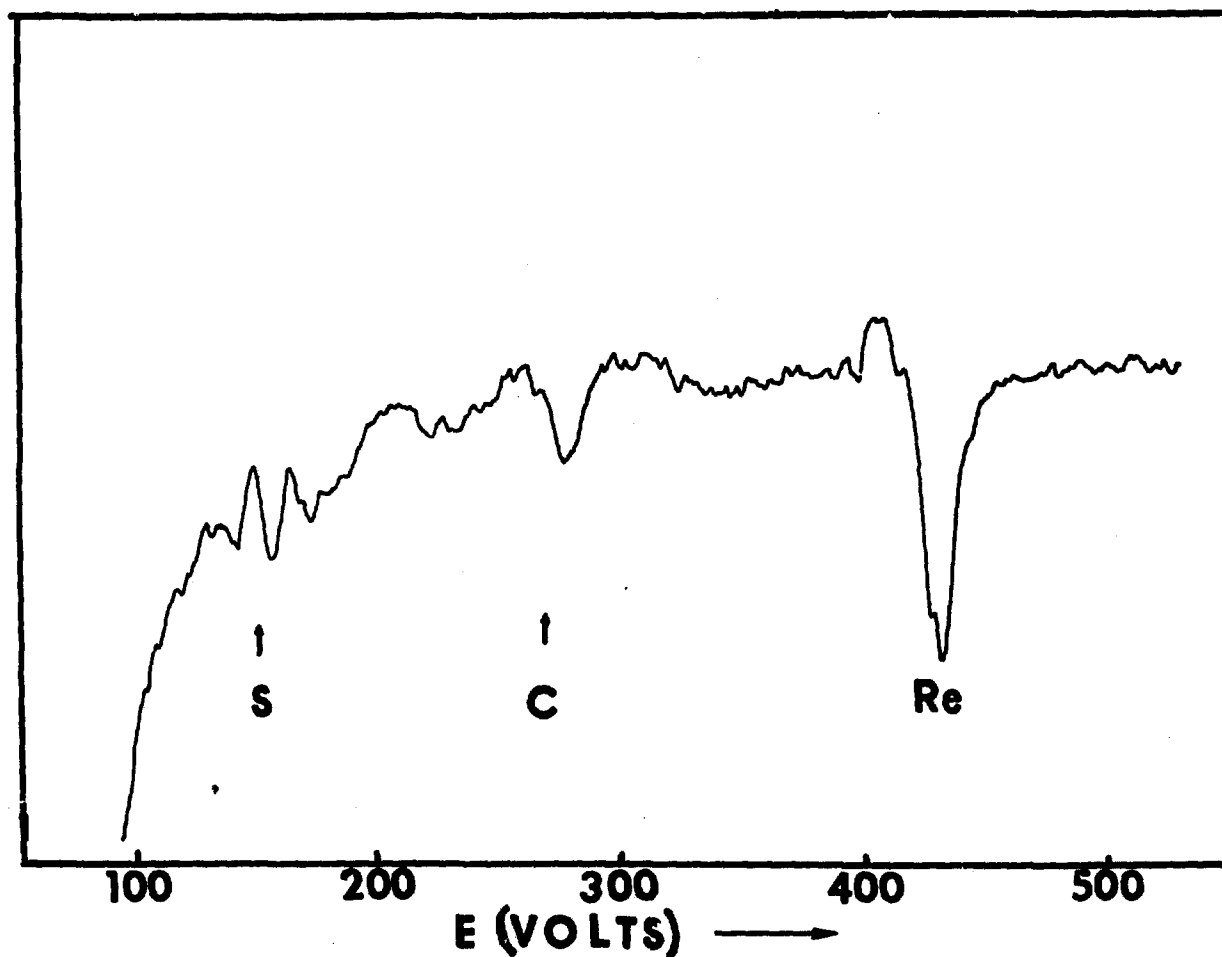


Figure 1. Derivative of the energy distribution of the inelastically scattered electron current vs. energy, E , from a contaminated rhenium foil sample. Principal contaminants are sulfur and carbon.

surface is possible. Heretofore, the principal problem in utilizing this effect for this purpose has been instrumental. Instrumentation for this purpose has now been designed, built, and operated in ARL's Chemistry Research Laboratory. The measurement is accomplished by using the fluorescent screen of the LEED optics to collect the inelastic electron current from the sample. The derivative of this current with respect to the voltage on the suppressor grid is measured electronically as the suppressor voltage is

scanned over the region of interest. Peaks in this curve correspond to the various Auger transitions, the size of the peaks being roughly proportional to the amount of material present for trace contaminants. An example of such a curve is shown in Figure 1 which gives the spectrum from a rhenium foil sample contaminated with sulfur and carbon. At present, it is capable of detecting impurities in quantities of about 0.1 monolayer; but lower levels, as well as quantitative analysis, are future goals.

chemistry

A PHOTOPOLYMERIZATION SYSTEM

At the Hughes Research Laboratories in Malibu, California, Dr. David Margerum and his associates, under an AFOSR contract, have been investigating the inhibition, initiation, and propagation of dye-sensitized polymerization reactions. These particular reactions are of much interest to novel photographic processing. Concurrently with this fundamental research being performed by Dr. Margerum, the research laboratory has been in the process of developing a photopolymerization system for photographic imaging which could be utilized in large screen information displays. A system was required which was as close as possible to a "real-time" display, with the time between recording and display as short as possible. Satisfactory progress was made on the mechanical aspects of the system; however, the photopolymerization process was not completely developed. The laboratory researchers could accomplish the initiation of the photopolymerization events which produced the image, but they lacked the means for stopping the process at the proper time. It was at this point that the basic-research results of Dr. Margerum's work became useful. This work involved the discovery that the ultraviolet photochemical formation of aci-anions in the monomer-dye-catalyst solutions could be used to decolorize the dyes and inhibit the photopolymerization. This was the inhibitor that the laboratory people needed to stop the processing in their photopolymerization system. Figure 1 demonstrates diagrammatically how the system works.

To start the chain of polymerization events, light

raises the dye molecules (photo-oxidant) to an excited state, thereby producing a stronger oxidizing agent than in the ground state. This species oxidizes the catalyst to the free radical that initiates the polymerization of barium acrylate. The newly formed polymer precipitates as colloidal particles that scatter light, producing an image. UV light, in the manner mentioned above, deactivates the unexposed solution with the help of a second photochemical system, thereby fixing the image.

Hughes has now developed the foregoing system to the point where it can take a picture, complete the photopolymerization process, and project the image in less than half a second.

These photopolymer systems have many potential military applications, such as in tactical display systems, large screen display systems, synthetic array radar processing, rapid data storage, and readout processes. Future applications might also include their use as intermediate recording media for scanning continuous beam (cw) lasers in display systems. It could also be used as a pulsed-laser, holographic recording medium with an immediate display of optically fixed holograms.

The foregoing accomplishments might not have been achieved but for certain fundamental research that was "sparked" by AFOSR support over 12 years ago. This was the work of Technical Operations, Inc. and of Dr. Oster at Brooklyn Polytechnic Institute which catalyzed some of the original basic research on the acrylic monomer and the photosensitive dyes that initiate the reaction described above.

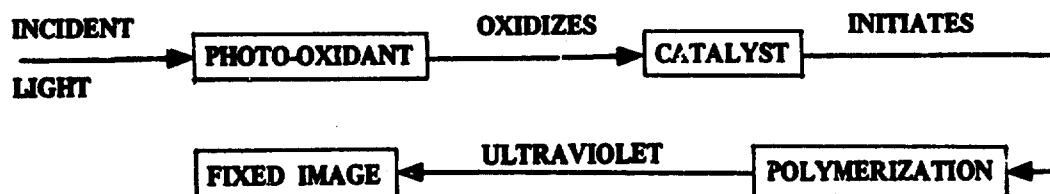
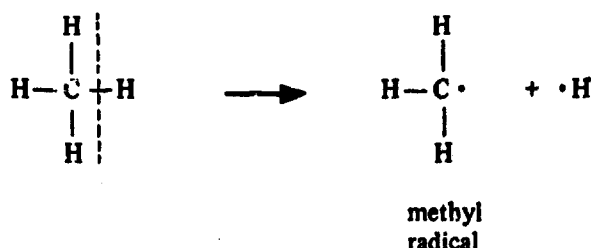


Figure 1

A NEW TECHNIQUE FOR FREE-RADICAL DETECTION

When a chemical bond is broken, one result of the fragmentation might be the formation of free radicals, i.e., reactive molecules with one or more unpaired electrons. To illustrate, the homolytic cleavage of a carbon-hydrogen bond in methane would yield a methyl radical:



Free radicals may be reactive intermediates in the synthesis of new materials, or they may be the breakdown products in the high-energy radiative degradation of a structural material, e.g., polymers. Usually, free radicals are very short-lived species (lifetimes of 10^{-3} to 10^{-8} seconds), and exist at low concentrations. Free radicals can be studied by electron-spin-resonance (esr) spectroscopy to yield information not only of the presence and number of unpaired electrons, but also of the distribution of the electrons in the molecule.

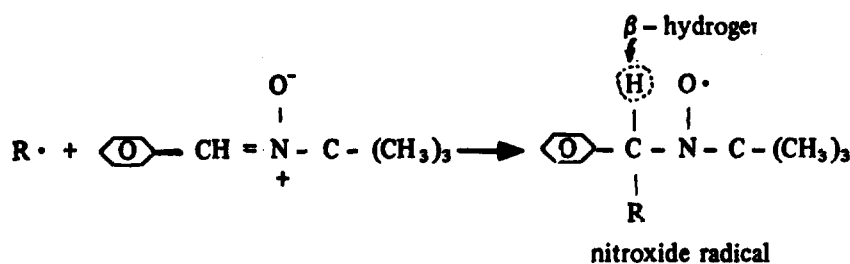
A need has existed for readily detecting and identifying low concentrations (below the esr threshold of about 10^{-8}M) of free radicals in reacting systems. With grant support from the AFOSR Directorate of Chemical Sciences, Dr. Edward Janzen of the University of Georgia has developed a trapping technique for this purpose. The approach is to have the free radical, generated at low concentration and

formed relatively slowly, react with a compound to produce a new and more stable radical easily detectable by esr. The nature of the resulting esr spectrum then provides information about the structure of the original radical. Dr. Janzen and his research group have found phenyl *t*-butyl nitron (PBN) to be uniquely suited for the identification of a number of short-lived free radicals by the formation of stable nitroxides.

Whereas the original radical ($\text{R}\cdot$) would have been difficult to detect, the esr spectrum of the resulting nitroxide radical provides information as to the structure of the radicals. (The structural information is obtained from the magnitude of the hyperfine splitting of the β -hydrogen as observed in the esr spectrum.) This approach has been used successfully to define the structure of the trapped phenyl, benzyl, methyl, trifluoromethyl, ethyl, *n*-butyl, acetoxy and benzoyloxy radicals.

Dr. Janzen's communications (References 1 and 2), and his presentations on the subject at the national meetings of the American Chemical Society in September 1968 and April 1969, have resulted in his receiving queries from researchers from various parts of the world. These people are asking whether Janzen's new free-radical trapping technique can be useful in determining if there are free-radical intermediates in the reactions they are studying.

This new method of detecting short-lived free radicals in low concentrations will be useful to the Air Force, not only in the synthesis of new materials through free-radical intermediates, but also as a sensitive technique for detecting the degradation of polymeric materials upon exposure to high-energy radiation of the upper atmosphere. Other general applications include the detection and characterization of free radicals in biochemical systems, polymerizations, and air-pollution studies.

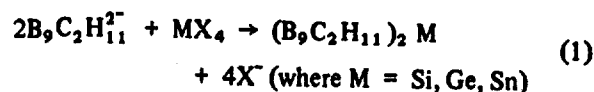


CARBAMETALLIC BORANES

High-temperature materials such as elastomers, adhesives, sealants, etc., are in continuing demand for aerospace applications. Since the carborane cage (Figure 1) is stable to above 500°C, it has the potential of providing a new class of high-temperature materials. Inasmuch as the carbons in the cage undergo many of the reactions of organic compounds, it appears feasible to incorporate this group (cage) into polymers for high-temperature application.

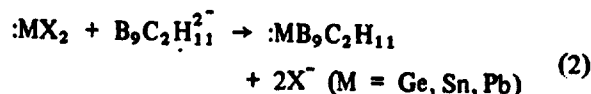
A new aspect of carborane research is the replacement of one of the B-H species with a metal atom to give a carbametallic borane (Figure 2).

As a segment of research on carbametallic boranes and their potential use as high-temperature materials, the reactions of four main-group IV metals (silicon, germanium, tin, and lead) with the dicarbollide ion, $B_{10}C_2H_{11}^{2-}$, have been investigated. Capts R. L. Voorhees and R. W. Rudolph at FJSRL anticipated that neutral species could be obtained by the following reaction:



However, the reaction did not yield the desired $(B_{10}C_2H_{11})_2 M$ species.

On the other hand, their subsequent work has revealed a remarkable new class of carbametallic boranes having a "bare" metal atom. These species result from the reaction of $B_{10}C_2H_{11}^{2-}$ with divalent group IV metal halides.



The reaction has yielded species with "bare" Ge, Sn, and Pb atoms pictured as occupying an apex of the icosahedron (Figure 2). This formulation is consistent with the characterization of these carbametallic species by infrared, nuclear magnetic

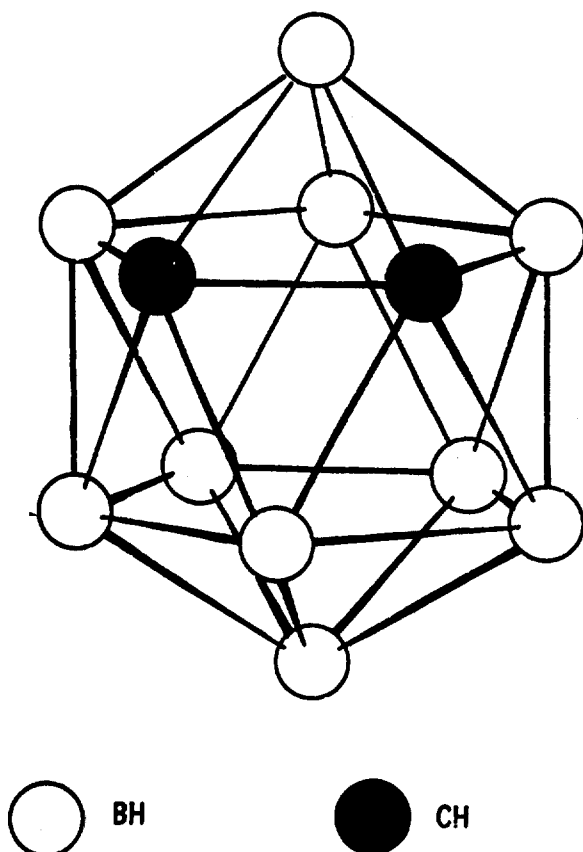


Figure 1. Carborane cage.

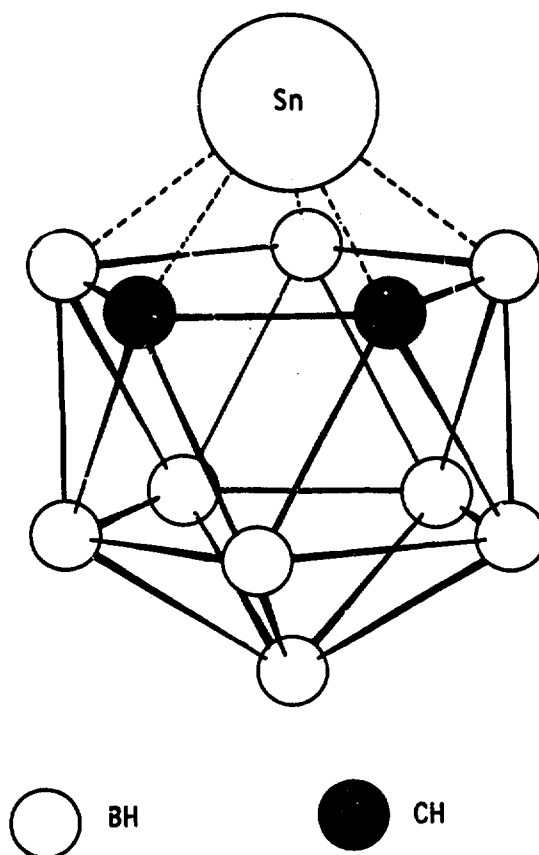


Figure 2. Carbametallic borane.

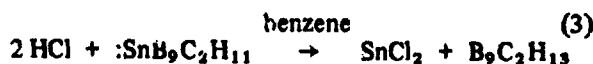
resonance (^1H and ^{11}B), mass spectroscopy and elemental analysis.

Thus far attempts to oxidize the $:\text{MB}_9\text{C}_2\text{H}_{11}$ species to $(\text{B}_9\text{C}_2\text{H}_{11})_2\text{M}$ have been unsuccessful.

As shown by equation (2), the method of obtaining $:\text{MB}_9\text{C}_2\text{H}_{11}$ species involves carbenoid reagents. Captains Voorhees and Rudolph are now attempting to extend this analogy and prepare a three-carbon carborane by the reaction of $:\text{CX}_2$ and $\text{B}_9\text{C}_2\text{H}_{11}^-$.

The lone pair of electrons on the metal atom in the $:\text{MB}_9\text{C}_2\text{H}_{11}$ species might be expected to show

some basic character. Thus far, however, no such evidence has been found. In fact, attempts to protonate the lone pair appear to lead to degradation.



On the other hand, there is evidence of the formation of $\text{Me}_3\text{N} \cdot \text{SnB}_9\text{C}_2\text{H}_{11}$ when $\text{SnB}_9\text{C}_2\text{H}_{11}$ is treated with trimethylamine, demonstrating the acidity of the metal. Undoubtedly the "bare" metal site in these species will impart a unique chemical character to the icosahedral cage.

chemistry

WHAT'S NEW IN NEUTRON DIFFRACTION?

The increasingly extreme environmental and operational conditions to which Air Force systems are subjected require that data, both fundamental and developmental, be obtained under comparable real or simulated pressures, temperatures, radioactivity and toxicity.

Dr. J. S. Kasper of the General Electric Research and Development Center, Schenectady, New York, under sponsorship of the Directorate of Chemical Sciences, AFOSR, is conducting a program to determine the changes in structure of materials produced by high pressure. He is using both X-ray and neutron-diffraction techniques in these studies. One of the significant accomplishments has been the development of a new neutron-diffraction technique using a pulsed linear accelerator (LINAC).

Neutron diffraction provides the potential of investigating a greater variety of materials than is possible with X-ray diffraction. There is an increased capability to locate hydrogen atoms and other light elements such as boron, carbon, nitrogen and oxygen in the presence of heavy elements. Neutron diffraction can also be used to distinguish between neighboring elements in the periodic table, such as In and Sb in InSb.

As with X-ray diffraction, the use of neutron diffraction to study extreme environments, such as high pressure, is restricted by the large amounts of shielding or heavy structural materials surrounding the specimen. However, Dr. Kasper, in conjunction with Mr. M. J. Moore of the General Electric Research and Development Center and Dr. J. H. Menzel of the Rensselaer Polytechnic Institute, has developed a new neutron-diffraction method for polycrystalline specimens that reduces these limitations.

The new method simplifies the construction of

the specimen container by using a fixed detector instead of a moving detector. This reduces the heavy-shielding limitations imposed by the extreme environment requirements; therefore, it has the potential of being less expensive, faster, and less complex than other neutron-diffraction techniques. The equipment includes a pulsed LINAC as a neutron source and a time-of-flight (TOF) detection system. This is the first application of a TOF system in conjunction with a LINAC, and the first reported use of accelerator neutron sources in neutron-diffraction studies of polycrystalline specimens.

The pulsing characteristic of the LINAC eliminates the need for an elaborate, expensive (\$50,000 to \$60,000) chopper which is required when a steady-state reactor is used as a neutron source. Since, without the chopper, there is no great loss of neutron flux, the new method is potentially a faster technique for obtaining diffraction patterns.

Figure 1 is a block diagram of the LINAC diffraction system used. The LINAC electron pulse is impinging on a tantalum target to produce a high flux of gamma rays. An isotropic distribution of high-energy neutrons results from the (γ, n) reactions in the target material. A collimated beam of neutrons is directed to one of three small ports in the B_4C -shielded cylinder, which contains the sample. The detector counters are placed at the second port, and at such an angle as to intercept the largest possible arc of the diffraction cone. The third port is for the diffracted beam.

Initial experiments on an NiO specimen resulted in a satisfactory diffraction pattern being obtained in four hours. The main features of the pattern, which were discernible in the first two minutes of operation, indicated that the flux of usable neutrons was relatively high. The raw data collected during the

four-hour run are shown in Figure 2.

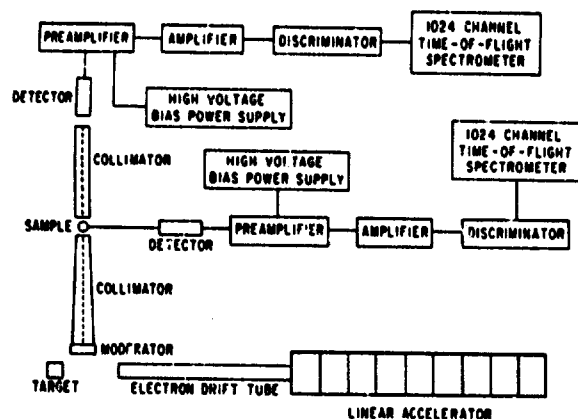


Figure 1. Pulsed Linear Accelerator-Neutron-Diffraction Instrumentation.

The measurements of d (interplanar spacings), which were limited by the accuracy of the flight-path measurement, were checked for internal consistency, with the result that an accuracy of 0.3% was indicated for lattice-parameter determinations.

Dr. Kasper's previous work in elucidating the polymorphic forms of boron are of particular significance to the Air Force because of current interest in boron- and graphite-reinforced composite materials. The development and use of new techniques, such as the pulsed LINAC neutron-diffraction method, will greatly enhance the fundamental knowledge of the structure of compounds containing light elements such as boron and carbon.

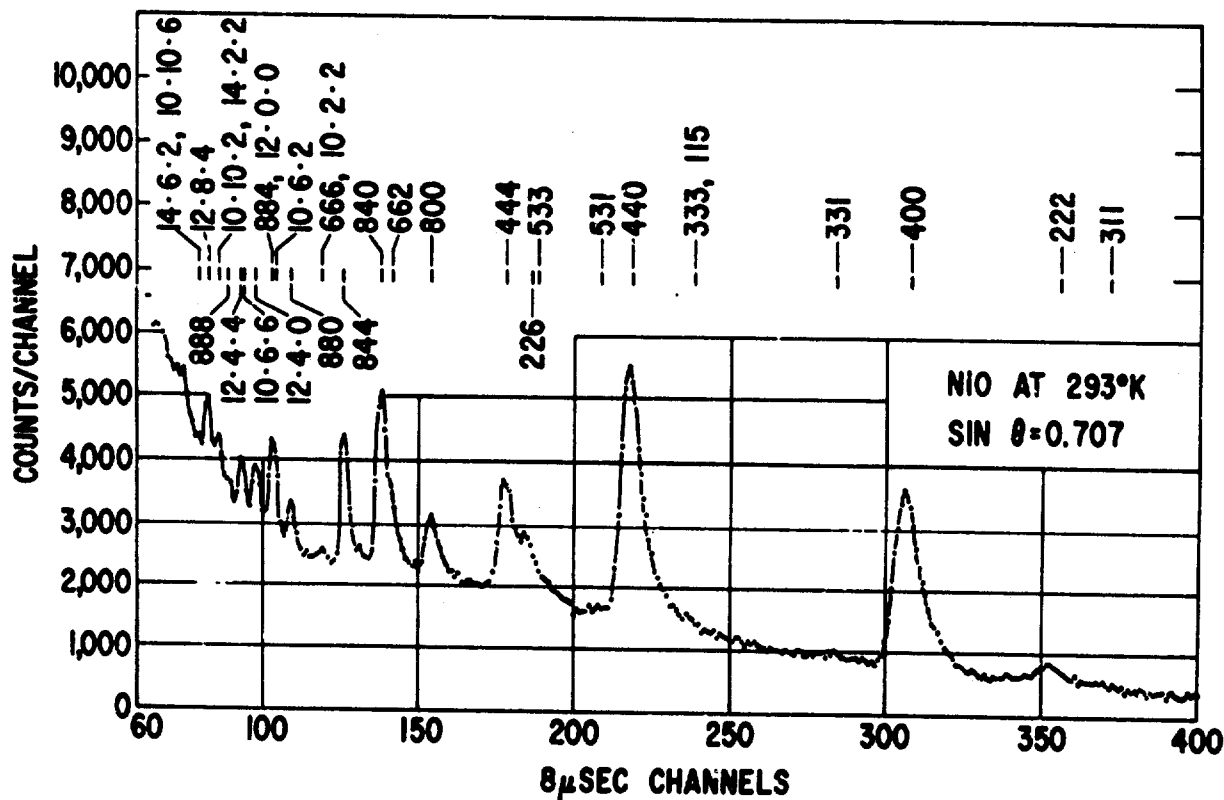


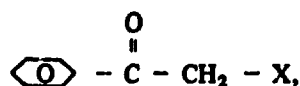
Figure 2. Four-Hour Run-NiO.

STABILITY OF MOLECULAR IONS

When a molecule enters the ion source of a mass spectrometer and interacts with the ionizing electrons in such a manner that a single electron is lost by the molecule, the ion that is formed is designated the molecular ion. The fate of this ion depends largely on the structure of the molecule and, in particular, on the ability of the ion to accommodate the positive charge.

At FJSRL, USAF Academy Cadets First Class J. J. Orgeron and J. J. Tobolski, under the direction of Major G. D. Brabson, Associate Professor, are investigating the influence of molecular structure on the stability of these molecular ions. Their research is supported financially by FJSRL, and reflects FJSRL's responsibility for stimulating in the Air Force Academy faculty and cadets an awareness of the importance of scientific research to the Air Force.

The current work is directed toward an investigation of the influence of the substituents in alpha-substituted acetophenones,



where X represents a variety of different substituents. In this particular case, the only effect that is expected to be important is the inductive (electron-attracting or -releasing) effect of the substituent.

At the outset, it was anticipated that the stability would be a linear function of the electron-donating capability of the substituent; this expectation was based on the hypothesis that electron-donating substituents would stabilize the resonance form which helps disperse the positive charge on the molecular ion. Electron-donating substituents would thus make the molecular ion less subject to fragmentation.

Although experimental results have verified general expectations, a simple linear relationship has not resulted. There appear to be numerous complicating factors, some of which are now being investigated.

chemistry

DENSITY MEASUREMENTS OF ALUMINUM CHLORIDE

The pure chlorides of aluminum and sodium exhibit markedly different degrees of expansion upon fusion; the coefficients of thermal expansion of the two liquids are also quite different. There is very little data available on the physical properties of the molten mixtures of these two chlorides. Conventional apparatus and experimental techniques are often not suitable.

As part of the research at FJSRL concerned with electrochemistry in molten salts, it was necessary to know the liquid and vapor densities of molten aluminum chloride-sodium chloride mixtures. The composition of a given AlCl_3 - NaCl liquid mixture in equilibrium with its vapor varies with temperature. It is therefore necessary to take vapor compositions and densities into account in measuring liquid compositions and densities for such melts.

Lt Col L. A. King and Major D. W. Seegmiller at FJSRL have devised a novel and simple technique for simultaneously measuring the liquid and vapor densities of volatile materials. For pure compounds, or for mixtures in which the equilibrium vapor composition is the same as that of the liquid, cells such as shown in Figure 1 are used. Two or more of the cells are used together at the same temperature,



W = Weight of Salt
V = Volume of Liquid
T = Total Volume
d = Vapor Density
D = Liquid Density

$$W_1 = V_1 D + (T_1 - V_1) d$$

$$W_2 = V_2 D + (T_2 - V_2) d$$

Figure 1. Cell for density measurements.

with pairs of simultaneous equations solved for the liquid and vapor densities at the particular temperature. For mixtures in which one component preferen-

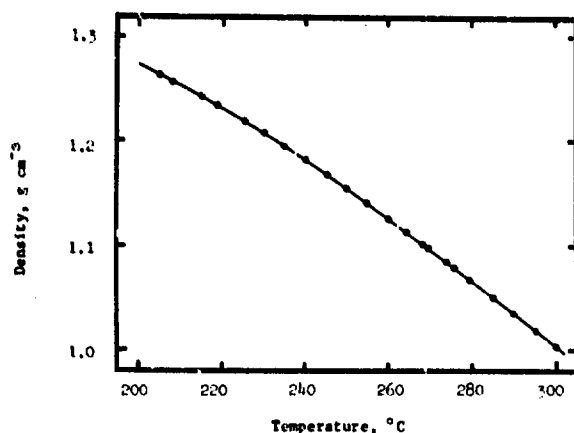


Figure 2. Density of Al_2Cl_6 liquid.

tially vaporizes, the procedures are similar, but somewhat more complicated.

Results for pure aluminum chloride are shown graphically in Figures 2 and 3. The small circles represent the experimental data, and the solid lines are calculated from least-squares-fit quadratic equations for density as a function of temperature. Over most of the temperature range, the equations fit the data with standard deviations for liquid and vapor of ± 0.00091 and $0.00043 \text{ g cm}^{-3}$, respectively. By a mathematical smoothing process on the measured liquid volumes (V in Figure 1), the two standard deviations are both reduced to $\pm 0.00015 \text{ g cm}^{-3}$.

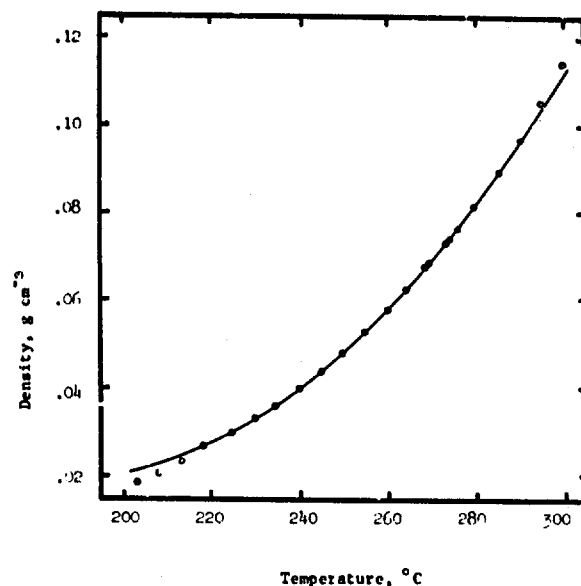


Figure 3. Density of Al_2Cl_6 vapor.

Measurements are being extended to include temperatures near the critical point of aluminum chloride, and to include AlCl_3 - NaCl mixtures. Vapor pressures also are being measured to determine an equation-of-state for Al_2Cl_6 vapor.

The technique should be applicable to the density measurements of all volatile liquids which are nonreactive with the cell itself.

chemistry

THE RELEVANCE OF POLYMER RESEARCH TO THE AIR FORCE

One of the most spectacular events in recent aviation technology has been the emergence of the first commercially produced carbon-fibre composite material for aerospace structural purposes. Hyfil, the Rolls Royce trademarked name for their carbon-fibre material, was based on the original fibre developed in 1963 at the Royal Aircraft Establishment Laboratory at Farnborough, England. Use of "Hyfil" in an epoxy resin base to fabricate the lower-stage fan and fan stator blades enabled Rolls Royce to design and construct the new and advanced jet engine known as the RB 211 which won the highly competitive contest and the multimillion-dollar contract to power the new Lockheed L-1011 "airbus."

This carbon-fibre material is extremely stiff, lightweight, and has a very high tensile strength. It has 4 times the strength of steel, and only one quarter its density. The 2 principal moduli control the frequencies of vibration of compressor blades and

enable the designer to develop blades far superior to those made of titanium in freedom from flutter. Due to the present high cost of the material, it will be used next in specialized structural materials, e.g., for helicopter blades, and in rocket and satellite applications. However, it is expected to be used in aircraft primary structures by 1973, and lead to weight savings on the order of 25% in a supersonic aircraft such as the Concorde. David Fishlock, scientific editor of the *Financial Times*, London, calculated that "If carbon fibres were used in the construction of the Galaxy, the world's largest aircraft, it could double its payload from 250,000 lbs to 500,000 lbs for the same gross weight of aircraft."

American, British, and Russian aircraft engineers and designers are racing to take advantage of the new material. The Royal Aircraft Establishment, Rolls Royce and the British Atomic Energy Establishment at Harwell did most of the early research and, later,

SPECIFIC PROPERTIES

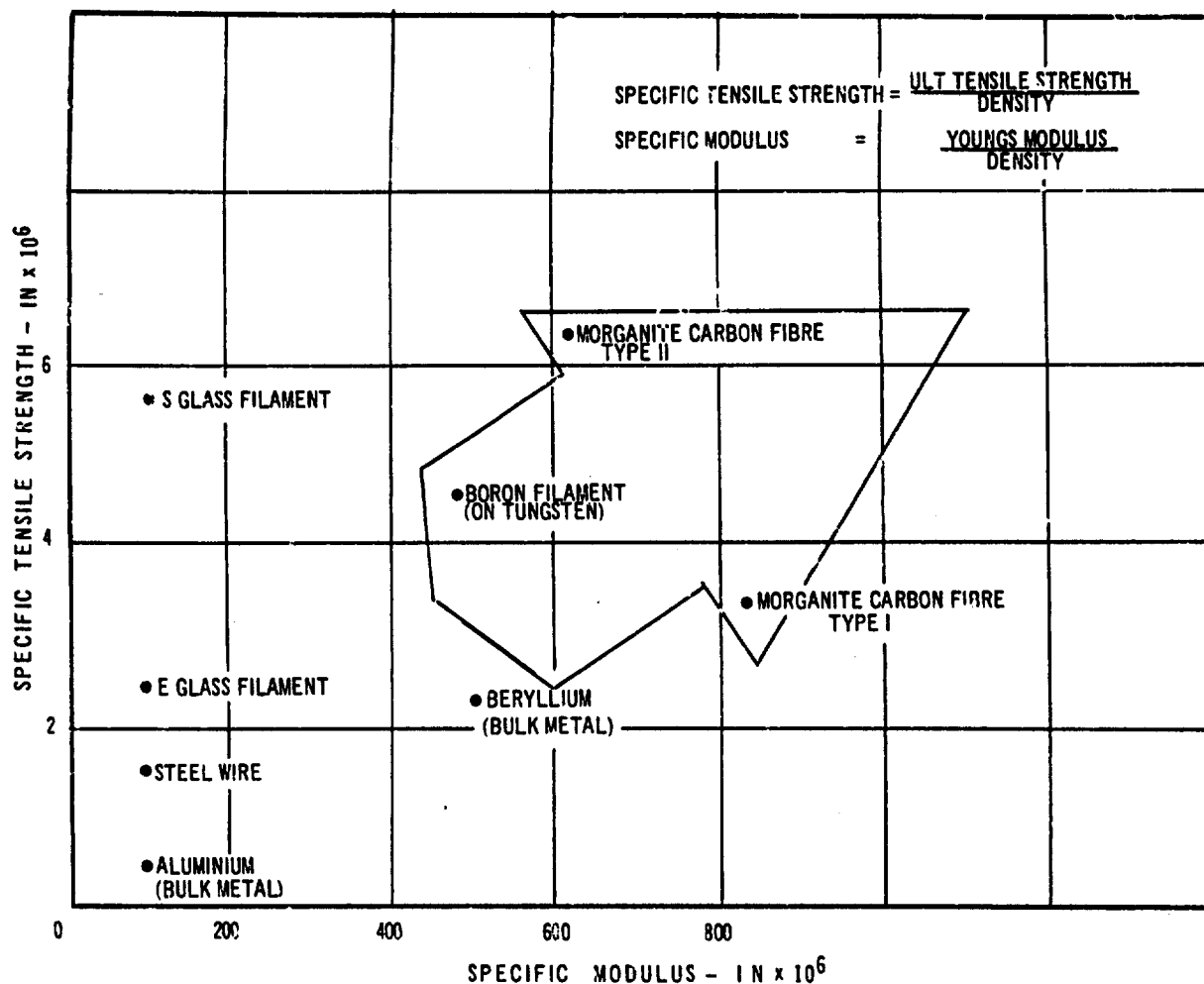


Figure 1. Specific Tensile Strength and Modulus of Carbon Fibres.

two companies, Courtaulds and Morganite, were licensed to manufacture the material. After much negotiation the California firm of Whittaker was also licensed by Morganite. The specific properties of the Morganite material are illustrated in Figure 1.

Returning to the title of this article, we may ask: what is the relevance of polymer research to this subject? Until very recently, little information was available on carbon-fibre development, since it had been one of the most successfully kept industrial secrets in recent times. About all that was known was that the carbon fibres were produced by a complicated stepwise carbonization from a polymer filament, probably polyvinylacrylonitrile. In spite of considerable research on carbon fibres all over the world, no other fibre developed could approach the strength and stiffness of the British material. In April 1969, in a short article (Reference 4) in *Nature*, W.

Watt, of the Royal Aircraft Establishment, revealed that the polymer-chain orientation of the fibres affected the course of the pyrolysis which was an intermolecular reaction controlled by steric factors. Thus, the ultimate properties of the carbon fibre were determined by the special pretreatment of the fibre and the steric orientation of the polymer chains in the original polyvinylacrylonitrile filament.

Professor Paul J. Flory of Stanford University, who this year published a book entitled *The Statistical Mechanics of Chain Molecules*, is probably the world's foremost authority on the stereochemistry of polymers. Ever since 1961, all of Flory's polymer research has been totally supported by AFOSR at an annual rate of \$100,000. Also, in the early 1950s, Professor Flory was the first Chairman of the Evaluation Panel of AFOSR's Directorate of Chemi-

cal Sciences, and helped initiate its very modest but extremely productive program in the physical chemistry of polymers. Flory's basic concepts in the stereochemistry of polymers have undoubtedly

guided the early British work, and can be expected to lay the foundation on which American industry will undoubtedly produce even better carbon composites as the aerospace structural materials of the future.

mathematical sciences

DISTRIBUTED PARAMETER CONTROL SYSTEMS

Recent developments in the theories of stability and control have been concentrated primarily on dynamical systems which are described by ordinary differential or difference equations. However, in many physical processes, such as in magnetohydrodynamic systems, aeroelastic systems, and nuclear and chemical reactors, the spatial energy distribution of the system is widely dispersed such that its dynamic behavior can be described adequately only by partial differential equations, integral equations, or functional differential equations. Also, in many control processes, spatially distributed feedback controls are used to achieve close regulation of the spatial distributions of certain dynamic variables of the system. These systems are commonly classified as distributed parameter systems. In the past few years, attempts have been made to develop theories for the stability and (optimal) control of distributed parameter systems.

During the past year, Professors P. K. C. Wang and D. M. Wiberg at the University of California, Los Angeles have been studying various fundamental aspects of stability and control of systems with distributed parameters. These studies, which have been devoted primarily to systems with known (deterministic) disturbances and parameters, have been pursued along the following main objectives: (1) to gain a fundamental understanding of the major problems in the stability and control of distributive systems; (2) to unify and extend the existing mathematical theories which have potential applications in this area; and (3) to assess the applicability of the theoretical results of the present investigation to problems of physical importance.

Results were obtained in the theory of optimal control for certain classes of distributive systems and for certain forms of performance indices which are of importance in applications. One of these more interesting applications is the problem of thermonuclear confinement. The necessary conditions that an optimal control must satisfy were derived for the problem of confining a thermonuclear plasma by means of external electromagnetic fields. Physical interpretations of the necessary conditions have also been obtained. Specific results were also obtained for the

plasma-confinement problem where the plasma is described by the Boltzmann-Vlasov equation and the external magnetic field is spatially uniform but time-varying.

Results have been obtained in the numerical solutions of distributive systems, and a simple method for approximating a finite set of first-order differential equations by a finite-state system has been established. Results have been obtained for certain special classes in the problem of establishing sufficient conditions for the asymptotic stability of equilibrium of distributed feedback control systems with probe sensors. Also, it was shown that an initially unstable hydromagnetic equilibrium of a highly conducting fluid or plasma may be stabilized locally by means of feedback controls in the form of a time-varying magnetic field depending on the fluid displacement from the equilibrium.

Professors Wang and Wiberg have extended the separation principle to linear-distributed parameter systems which can be represented by a complete set of orthonormal vector eigenfunctions. Their work on probe-sensor and controller locations has led to the conjecture that it is usually better to locate the sensor near the controller, if the noise is small, and near the noise otherwise.

Professors Jack K. Hale and Ettore F. Infante of Brown University have completed a study of a general type of dynamical system which is an attempt to characterize those properties of the solutions of partial differential equations which lead to an invariance principle. Professor Infante has been studying some dynamical systems described by partial differential equations in an attempt to obtain stability results using the fundamental ideas of the Liapunov direct method. A considerable amount of work has been done on the Navier-Stokes equations for incompressible fluids.

Professor H. J. Kushner, also of Brown University, has published his work on optimal control of a linear distributed parameter system with white noise inputs. He is currently extending the problem to handle the case of measurement noise.

Professor A. V. Balakrishnan of the University of California, Los Angeles has developed a new technique for computing optimal control problems. The results obtained for this "epsilon" problem in the case of boundary control for partial differential equations appear to be new, and the limiting case provides a new method of establishing the character

of the optimal control law.

The above are only a few of the many aspects of distributive parameter control systems now being studied and supported by AFOSR(OAR). The desired goal is to develop the state-of-the-art in distributed parameter systems to a point where it is equivalent to the state-of-the-art in ordinary control theory.

mathematical sciences

DEGREE OF APPROXIMATION BY POSITIVE LINEAR OPERATORS

It is very often necessary or more convenient to approximate a given function by one which is simple in some respect. For example, in representing a complicated function on a computer, one often uses a polynomial or a ratio of polynomials to represent the original function because of the ease with which a polynomial can be generated and manipulated by the computer. In such cases it is essential to know how well the original function is approximated. The mathematicians of the Applied Mathematics Research Laboratory at ARL, Drs. Oved Shisha and Benram Mond, have developed a quite general formula which estimates the degree of approximation to continuous functions by polynomials and trigonometric polynomials, and also the degree of approximation to functions which have been transformed by some operation. This was done by recasting Korovkin's results on linear positive operators into a quantitative form. The results are quite general and appear to be a major advance in approximation theory.

Mathematical operators represent a quite general concept. One can consider that any transformation is an operation: e.g., differentiation or integration are operations, etc. The concept of an operator encompasses a very large class; thus, theorems regarding operators have a very large domain of applicability.

The work done here tells quantitatively how well one can approximate the result of such general operations by polynomials. The measure of just how good the approximation is may be given by calculating the "norm" of the difference between the results of the operation and the approximating polynomial, i.e., the distance between the two functions measured in some prescribed manner. The concept of a "norm" is also quite general and permits the distance measurement to be made in many different ways. The operators in question must be linear positive operators which operate on real functions (vis-à-vis complex functions) which, in turn, are defined for all real numbers. These real functions must be everywhere continuous and periodic with a specified degree of continuity. Then, so long as the operators acting on the functions 1, $\cos x$ and $\sin x$ result in bounded functions, then a specific bound can be given for the difference between the approximated function and the map of this function by means of the operators.

The results described above were published in the 1968 *Proceedings of the National Academy of Sciences*, and in the *Journal of Approximation Theory*. Other workers have already used this theorem to obtain additional new results.

mathematical sciences

COMPUTATIONAL ASPECTS OF A UNIFIED APPROACH TO PROBLEMS IN ESTIMATION AND DETECTION

As technology advances along some front, a level of sophistication is encountered which requires a consideration of stochastic (i.e., random) phenomena for refined analysis. In modern communication and control systems, the use of many techniques for statistical inference is now classical, with the major classifications for such techniques being decision theory and estimation theory. The general problem in decision theory is to perform an observation having a

stochastic nature and to decide among the possible causes which produced it, while the estimation problem consists of determining values for parameters or processes of interest which are observed only remotely.

It is usually possible to formulate a problem of statistical inference in communication or control as consisting of an observed process, which is the sum of a signal process and a noise process. In the more

familiar problems, the signal is a known waveform, or else the signal is described by a few unknown parameters. However, the more complex situation in which the signal process itself is stochastic in nature has more recently become of interest (see, e.g., Reference 1).

Communication systems now employ media such as troposcatter, meteor trails or auroral and orbital chaff belts—randomly varying channels—which give rise to the reception of a stochastic signal. For purposes of secure communication, a message may be encoded by random processes, hence generating a stochastic signal-detection problem for the receiver. In radar and sonar systems used against dispersive targets, the stochastic signal-detection problem again arises in processing returns. Radio telescopes and seismic-detection systems utilize detectors for noise-like sources. Guidance and control systems which are subject to time-varying disturbances require an estimation of nonstationary stochastic processes to effectively perform in the disturbed environment. In estimation problems for control, the stochastic signal process is usually the plant output itself. Pattern recognition also may be formulated in terms of stochastic signal estimation by viewing the signal as the statistics of a data subclass.

A rather large class of the situations mentioned above yields a mathematical formulation in which the signal and noise stochastic processes have known covariance functions of the "separable" form. In this separable form, a covariance function $R(t,s)$ is decomposed as a finite linear combination of terms of the form $a_i(t)b_i(s)$, $s \leq t$, and $b_i(t)a_i(s)$, $t < s$, where $a_i(\cdot)$

and $b_i(\cdot)$ are functions of a single time argument. Specification of the covariance function for (zero mean) stochastic processes allows treating estimation problems in the "wide-sense" and detection problems for Gaussian processes. That such a covariance function is known includes the possibility that sufficient data is available to accurately determine the separable form by empirical methods.

The research conducted by Major Roger A. Geesey of the Aerospace Mechanics Division, FJSRL, has determined mathematical techniques which are effective in solving both estimation and detection problems in terms of a formulation with separable covariances. This research, reported in References 2 and 3, has enlarged the body of mathematical theory applicable to estimation and detection by allowing a less-detailed problem formulation and by giving more effective digital computational methods for solutions. Also, the research has shown more clearly that the understructure for problems in estimation and detection is common to both and consists of modeling an observed stochastic process as the output of a causal linear filter, driven by white noise, which is invertible on an arbitrary, finite-time interval. The significance of invertibility in such a model for an observed process is that the observation may then be easily "whitened" and the solutions for estimation and detection obtained by solving the simpler problem based on white-noise observations. "Whitening filter" techniques have been used previously in engineering with a great deal of success. This research has extended their utility to a broader problem formulation, as described above.

mathematical sciences

SIMILAR SOLUTIONS FOR BOUNDARY-LAYER PROBLEMS

Many problems that arise in the investigation of flows at very high velocities, i.e., velocities on the order of the speed of sound, which are important for aerospace applications, are closely related to problems whose solutions depend on the examination of differential equations arising from the boundary-layer theory of fluid mechanics. One example would be the drag experienced by an airplane wing or turbine blade. In particular, the study of solutions of differential equations arising out of the basic theory can often be treated through a study of "similar" solutions of boundary-layer equations,—that is, through a study of solutions known to yield "similar" velocity profiles.

Professor James Serrin of the University of Minnesota, under a grant from the Mathematics Division, AFOSR, has investigated various problems

in laminar boundary-layer theory. In two recent papers (1,2) written jointly with Professor J. B. McLeod of Oxford University, the existence and behavior of "similar" solutions were examined under given sets of conditions. This research concerned the boundary layer which occurs in the natural convection of the incompressible fluid adjacent to a heated vertical wall, and the boundary layer formed by a compressible fluid flowing past a fixed boundary surface. In both cases "similar" solutions of the underlying partial differential equations governing the fluid motion were considered.

The major contributions of this research by Professor Serrin come from his establishing, on a mathematical basis, that the ordinary differential equations which arise in connection with problems of this type do in fact have solutions satisfying the

appropriate boundary conditions. In addition, he has provided a mathematical description of the behavior of the solution to the compressible-fluid problem. These results are important for providing a basis for

the solution to (or additional insight into) many problems of Air Force interest which are related to differential equations arising from boundary-layer theory.

mathematical sciences

A PRACTICAL APPLICATION OF ABSTRACT MATHEMATICS

In the evaluation of new polymers (plastics) for use in such aerospace applications as ablation layers, drogue parachutes, and honeycomb cores, a property of considerable interest is the substance's molecular-weight distribution (MWD). This function shows what fraction of the polymer's molecules have a given molecular weight. Generally speaking, if a polymer's molecules have mostly large molecular weights, the material will consist chiefly of long "chains" of atoms, and its physical properties can be expected to be superior to those of a plastic with many "short" molecules of lower molecular weight.

The ultracentrifuge is often used to obtain information about the MWD of a polymer. The material is dissolved in a solvent, and the solution placed in an ultracentrifuge cell. Molecules with higher molecular weights are separated from those with lower molecular weights by the action of the ultracentrifuge, and it is possible to obtain an integral equation (1) relating the steady-state concentration gradient in the cell, which can be measured quantitatively with the aid of a schlieren optical system, and the desired MWD.

Several schemes have been proposed to treat this integral equation, i.e., to compute numerical values of the MWD from observed values of the concentration gradient. Unfortunately these schemes have often proved disappointing when applied to practical problems, and other schemes, which use data from runs at several ultracentrifuge rotor speeds, have been suggested. (1,2) While such schemes have enjoyed some success, there is the drawback of having to wait for steady-state conditions at several rotor speeds; this may take weeks at each speed.

In a recently completed study of the integral equation for determining an MWD from a run at a single rotor speed, Dr. David A. Lee at ARL's Applied Mathematics Research Laboratory has shown that

certain theorems developed in the abstract study of integral equations have somewhat surprising implications for the MWD problem.(3)

First, the integral equation involved does not necessarily have any solution at all, if certain functions are chosen for the concentration gradient. More distressingly, given any concentration gradient for which the problem *has* a solution, there is another function, which differs from the first by less than any preassigned amount over the interval in which the experiment gives information, for which the problem does *not* have a solution! From a formal point of view, this state of affairs is fatal to any attempt to determine MWDs from runs at one rotor speed, since every experiment involves some error. On the other hand, as a practical matter, it hardly seems reasonable that a "very small" error would utterly ruin any scheme for inferring the MWD.

By applying further theorems from the theory of integral equations, Dr. Lee has been able to reconcile these two views of the problem. The fact of the matter is that, if one attempts to find the coefficients of any series representation for the unknown MWD (power series, Fourier series, etc.), the slightest experimental error which places the recorded gradient outside the class for which the equation has a solution will produce arbitrarily large errors in the higher coefficients. However, a finite number of expansion coefficients can be determined with finite error.

This information can be used to design experiments so that "enough" expansion coefficients can be determined with acceptable accuracy. Work continues on the practical determination of MWDs in cooperation with Drs. M. T. Gehatia and Donald Wiff of the Nonmetallic Materials Division, Air Force Materials Laboratory, AFSC, at Wright Patterson AFB.

THEORETICAL AND EMPIRICAL PREDICTIONS OF INTERNAL CONFLICT BEHAVIOR

Quincy Wright, an early investigator of wars and their causes, (1) once made the statement that "a theory, if not applied to actual data, remains unconvincing." (2) In the context of many abstract social theories, each purporting to explain some facet of human interaction, and the explicit or implicit reliance on some of these theories for decision-making and long-range planning, such a statement as Wright's is pregnant with implications.

Such an effort (3) to apply theory to the data was undertaken by Gary L. Buck and Alvin L. Jacobson who were Cornell University graduate sociology students at the time. They attempted to operationalize a theory of development postulated by Talcott Parsons. (4) It was believed by the Office of Research Analyses, OAR, that further development of their effort could provide insights of value to those planners and decision-makers interested in the future potential for internal conflict. Thus, Gary Buck, then at the University of Texas at El Paso, was asked to extend the initial work to a test of theory based on data from all nations of the world. These additional results further confirmed the utility of the approach. (5)

Basically, Parsons' original theory postulated that societies were composed of 10 critical elements which he labelled "universals," and that these elements were intertwined in a way which was crucial to the understanding of the development of nations. These "universals" were such aspects of society as the legal system, bureaucratic structure, the economic system, kinship structure, and others, and can be generally defined as organizational developments sufficiently important to the further evolution of societies as to be "hit upon" by various social systems operating under different conditions. (4) Further, Parsons postulated that, as societies evolved as recognizable social groupings, they followed a pattern of development on each of the 10 "universals" in a specific order. The hypothesis, as extended by Buck and Jacobson for their static operational analysis, became: "If a primitive society follows the process proposed by Parsons, why would one not expect a repetition of a similar sequence of development at a higher level?" (5) Thus, the hypothesis becomes one in which development is an ordered, iterative process across the 10 "universals" at ever higher levels of development.

The operational analysis led to a search for various indicators of each universal for which information from the "real world" could be gathered to measure a nation's level of development on each

universal. Guttman scalogram analysis was then applied to the data which, if the hypothesis is correct, can identify from the data a specified order across several levels, such as was postulated by the theory. The operational hypothesis was confirmed, implying that such a process of social development as had been postulated was supported by the data from the real world.

Having obtained promising results thus far, a further analysis was deemed appropriate. The Office of Research Analyses (ORA) brought together the team of Assistant Professors Gary L. Buck and Manus I. Midlarsky from the Universities of Arizona and Colorado, respectively, and Major Eugene A. Erb, Jr. of ORA to apply additional statistical tests to the data, to the validity of the theory, and to a determination of the ability of the theory to predict the incidence of a variety of manifestations of internal instability. The question asked at this stage was whether the operational theory could yield any predictive insights on the prospects for internal instability within nations. The stepwise multiple regression technique was used to uncover the linkage, if any, between predictors and criteria. The values for the universals were used as independent variables or predictors. Information gathered by the Feierabend's, (6) consisting of frequency counts on a variety of forms of internal instability events ranging from revolutions to riots, was used as a set of dependent variables or criteria. Results of this analysis demonstrated that such predictive potential did exist, in some cases to a high degree, and thus insights for further theoretical revision were obtained. (7) The results were sufficiently promising to justify sponsoring further research using time-series data. This effort is presently under way at the University of Arizona under the direction of Assistant Professor Buck.

Several implications of the effort are worth mentioning.

First, insights into priorities for national strategies in support of U.S. objectives are suggested. Different strategies can impact on different elements of the recipient societies. Based on the results of analyses to date, it becomes clear that certain strategies (inputs) are more apt than others to generate a higher incidence of certain forms of instability (outputs) in a given system. Thus, such an analysis allows more explicit consideration of the social interactions resulting from programs in support of these strategies, with a potential improvement of the overall value of U.S. strategies and the success of our objectives.

Second, the research to date demonstrates the feasibility of empirically analysing theories which underlie assumptions inherent in the planning process. Since the more specific requirements which need to be supported by strategy, tactics, missions, R&D funding, alliances, basing, etc., are deduced from these key assumptions, they deserve a frontal assault on their validity for fundamental policy. The potential for such an assault exists.

Finally, the insights available from such analyses permit an improved awareness of certain key parameters which can reduce some of the uncertainty about the international system and its members. Such insights are useful for pinpointing needed research which can further reduce uncertainty, and for provid-

ing a more reliable "scenario" of the future on which specific systems-analyses and operations-research problems are based.

One further qualification is in order. This research is not founded on any belief that the uncertainty inherent in the future activities of humans and their institutions can be eliminated. Rather, it is based on an awareness that such uncertainty can, at certain times and with respect to certain situations, be reduced. Since certain assumptions concerning the future are, and must continuously be, used at all levels of analysis and planning, it is important to improve the theoretical foundation of such assumptions. Other relevant theories with policy implications exist. The theory described was only one among many available for fruitful study.

mathematical sciences

ADAPTIVE COMMAND-SYSTEM MODELS

Though no evolutionary forces have changed man radically over the past 100 years, man has nonetheless radically changed the complexity of his environment through the technologies he has produced during this period. His environment has become increasingly information rich, and requires an ever-greater number and variety of machines that are able to digest this information intelligently and reduce it to a volume he is able to cope with. Decision-makers in military and other large-organization environments are particularly beset not only with large information flows, but also with short-time requirements, conflicting demands, and incomplete or ambiguous information, frequently on priority items.

One of the objectives of basic research in the information sciences is to analyze the information-processing requirements in such complex environments, and to develop methods for handling large amounts of the information flow automatically. Results that are accumulating from research on the nervous systems of living organisms are suggesting analogies between the organization and operation of these systems and structures and flow patterns that might desirably be incorporated into military and social systems. One of the subassemblies of nervous systems that plays a particularly critical role in living organisms is the reticular formation (RF). Its character as an overall commander appears especially relevant to the design of adaptive command and control systems in military and management contexts.

Dr. William L. Kilmer of Michigan State University has been developing models of RF performance under an AFOSR grant. The models are based on the hypothesis that the core of the RF is the structure in

vertebrates that commits the animal to one or another mode of behavior. The RF is believed to command by issuing signals that effect integrating behavior among the various organs and parts of the brain. The RF commands and controls the mode of operation of the organism's other computers.

How the mode decision is made is regarded by Dr. Kilmer as the RF *command problem*. The other aspects of RF operation—the integrative ones that subserve the generation of autonomic rhythms, reflex control of the body's housekeeping systems, filter tuning in the sensory pathways, etc.—are the RF's *control problem*.

Dr. Kilmer's work is aimed at the formulation of a theory of the RF that is able to explain how the RF core, containing on the order of 1,000,000 neurons, can reach a workable consensus as to the proper mode of total commitment in a fraction of a second. He sees the possibility that this theory will lead to the development of a relational calculus for describing what the RF does, and how it does it. John von Neumann anticipated the need for a new mathematics for characterizing the structure and operations of machines having the information-processing potentials of man and his nervous system. Dr. Kilmer's research, which has taken account of the neuro-anatomical, physiological, phylogenetic, ethological, and clinical research of others, gives encouraging evidence of slow but progressive achievement toward both theoretical and practical goals. Intelligent machines capable of handling large complex inputs appear realizable; but they will probably be closely paced by advances in mathematics and biology as well.

mathematical sciences

GRAPH THEORY

The theory of graphs has become quite an important development in theoretical and applied mathematics. Areas of application, which rely upon the establishment and extension of a mathematical basis in graph theory, encompass network synthesis and analysis (including new computer-systems hardware, software, and networks), theoretical physics, organic chemistry, social psychology, and operations research. The Applied Mathematics Division, AFOSR (OAR) has supported research efforts directed toward the expansion of the field of knowledge in graph theory and its applications for several years.

Professor Frank Harary of the University of Michigan has been engaged in research concentrating on the areas of graphical enumeration, topological graph theory, and graphs and matrices. He has recently completed a book entitled, *Graph Theory*, to be published by Addison-Wesley, which is based on his investigations of various phases of the theory of graphs and its applications. While the book concentrates on theorems, he feels it should be very useful as a reference text for those working in fields which involve applications of graph theory. (Professor Harary is also editing another book, *Proof Techniques in Graph Theory*, Academic Press, to appear this year.)

Professor Harary's efforts in the area of graphical enumeration have led to a compilation of unsolved problems in the field, together with a summary of all of the solutions to combinatorial-enumeration ques-

tions which have been obtained. The resulting papers have aroused considerable interest, and several solutions have been obtained by various scholars.

Research on topological graph theory originally stemmed from a practical question involving the number of layers required for a printed circuit with a given number of nodes so that no pair of electrical elements would intersect. These considerations led to the concept of the "thickness" of a graph, G , which meant the minimum number of planar subgraphs whose union was G . In turn, other topological invariants of a graph were investigated, namely the genus and the crossing number. The genus of a graph, G , is the minimum genus among all orientable surfaces such that G can be embedded on such a surface with no pair of its edges intersecting. The crossing number of G is the smallest number of pair-wise intersections possible when G is drawn in the plane.

In some of Professor Harary's earlier work, the approach to the study of a matrix by exploiting the structural properties of its underlying directed graph has been found to be most useful in connection with the inversion of sparse matrices. A later study of determinants using their underlying graphs has led to mathematical results which have been applied in electrical-circuit theory. Also, in recent research, operations on matrices have been linked with different ways of combining two graphs to construct a composite graph.

mathematical sciences

DYNAMIC PROGRAMMING AND THE SOLUTION OF A SEARCH PROBLEM

A problem in dynamic programming is specified by a set of states of some system, a set of available acts, a law of motion, and a reward function. The law of motion is of the following nature: when the system is in a given state and a certain act is chosen and effected, the system moves to a new state selected according to an associated probability distribution. The objective in solving a problem in dynamic programming, given a start of the system in some initial state, is to maximize the total expected income of the infinite future.

On the other hand, a search problem is specified by a finite set of locations in which an object may be found, and three functions defined on that set: (1) the probability that an object is at a given

location; (2) the cost of a single search of a given location; and (3) the probability of finding an object which is at a given location. The objective in solving a search problem is to find an object at minimum expected cost.

Professor D. Blackwell of the University of California, Berkeley, under a grant with the Mathematics Division, AFOSR(OAR), recently solved a search problem by considering it as a problem in dynamic programming and applying Bellman's optimality principle. As he sets forth: the states are simply the probability distributions (1), together with a special terminal state to which the system moves when the object is found. The acts are simply the locations: to choose an act means to search a given

location. If the system is in a given state and a certain act is chosen and effected, there are two possible next states: if the object is found, the next state is the terminal state; however, if the object is not found, the next state is determined by the "conditional distribution of location," a function composed of the probability distributions (1) and (2). The reward is expressed in terms of the cost function (2).

In this context, Professor Blackwell's solution may be simply stated as follows: given a certain state of the system, the expected total cost is minimal if a search is made for in which function (1) times function (2) divided by function (3) is maximal.

The results are extended to moving objects, i.e., by considering that motion as a Markov process with a given transition matrix.

mathematical sciences

EVALUATING FORECASTS

The real issue confronting the decision maker is how to evaluate a forecast, which is presented to him as decision information, before he actually makes his decision. Will it result in a good decision or a bad one? A current Office of Research Analyses effort has been aimed at helping the decision maker resolve this question. This has brought forth an interim product, a "Consumers Checklist" for forecasts which takes the form of a series of questions asked in a specific order. The intent is to systematically unravel the thought processes which have led to the forecast. The questions are as follows:

1. *Why do we need this forecast?* This requires a clear-cut definition of who "we" are. Specifically, what individual or organizational entity is making the decision? What decision, among what alternatives, is to be made? What time frame does the decision cover? How important is the decision to us?—to our continued survival?—to our efficient operation?—to our comfort or convenience?

2. *What portion of the needed decision information does the forecast project?* This requires a definition of those items of information which must be taken into account in making the decision. Which of these does the forecast cover? Does it include facts about our own operation? Does it take into account possible changes in our own outlook and values over the forecast period? What external actors have the power to influence the outcome of the decision? Does the forecast take into account their likely attitudes, values, and actions? What items of necessary decision information have been excluded from the forecast?

3. *What method was used?* Here a one-word descriptor or label is not enough. The method should be described in detail. Was it done by extrapolation or by analogy?—or by a combination of the two? Was the processing of the input information done by intuition, expert judgment, consensus of experts,

Delphi, etc.? It is essential that the decision maker be aware of the strengths and weaknesses inherent in the forecast resulting from the inherent capabilities and limitations of the method used. In particular, he must avoid such mistakes as allowing a six-color graphical display with transparent overlays to conceal the fact that the forecast is based on the judgment of a single person who is competent in only a small portion of the area of concern.

4. *What are the assumptions?* In the absence of facts, assumptions must be made about certain portions of the total set of decision information. Identifying what these assumptions were may be difficult, but it is necessary. In particular, if an explicit method of forecasting has been used, it allows the decision maker to determine the effect of changing assumptions on the outcome of the forecast. Otherwise, he has no chance to evaluate the forecast in detail, but must accept or reject it as a whole.

5. *How well have the assumptions been tested?* This is an important point, but one sometimes overlooked. Even though assumptions are used in place of facts, they should be supported to some extent by empirical evidence. Many assumptions, far from having "stood the test of time," have in fact stood only because they were never tested. Care must be taken to avoid these.

6. *Annotation of data sources.* This is more than just an attempt to satisfy scholarly canons. It is essential in order to allow back-checking and to meet the requirements of replicability. It also permits the decision maker to take into account the known biases of certain information sources.

The questions in this Checklist represent the sort of information any decision maker should have concerning a forecast which he may have to use. More complete analyses of forecasts are possible, but the methods for carrying out such analyses are still in the research stage.

MICROWAVE ACOUSTIC SURFACE WAVES

Microwave acoustic waves are of considerable utility in the design of signal-processing, radar, and ECM (electronic-countermeasure) devices. Recently, Dr. P. H. Carr and Lt. A. J. Slobodnik, Jr. of AFRL's Microwave Physics Laboratory have obtained much needed quantitative data on acoustic propagation losses. Measurements have been made for the first time in single-crystal LiNbO_3 up to 2 GHz. In addition, surface-wave delay lines have been operated up to 3 GHz, and the practicality of using microwave acoustic surface waves in the low microwave region has been demonstrated.

One of the experiments performed by Lt. Slobodnik is illustrated in Figure 1. Electromagnetic energy is converted into surface acoustic energy at an input interdigital transducer. It then propagates along the crystal with a velocity 5 orders of magnitude

slower than light (resulting in a time delay of 2.8 $\mu\text{sec}/\text{cm}$), and is reconverted into an electromagnetic signal at the output transducer. To measure the loss, a laser beam is reflected off the sound column. In addition to the direct reflection, a small portion of the light is deflected to side lobes due solely to the presence of the sound beam. This deflected light is detected by a photomultiplier tube, and the decrease in light intensity as the laser is scanned down the acoustic beam is a direct measure of the acoustic loss. Typical values for this loss are 2.85 - 4.65 dB/cm at 1 GHz, and 9.9 dB/cm at 2 GHz, a lower loss per wavelength than occurs in either coaxial cable or microwave waveguide. In addition, it has been determined that operating delay lines in the atmosphere contribute an additional 10% to these losses, a fact having important consequences for the design of operational devices.

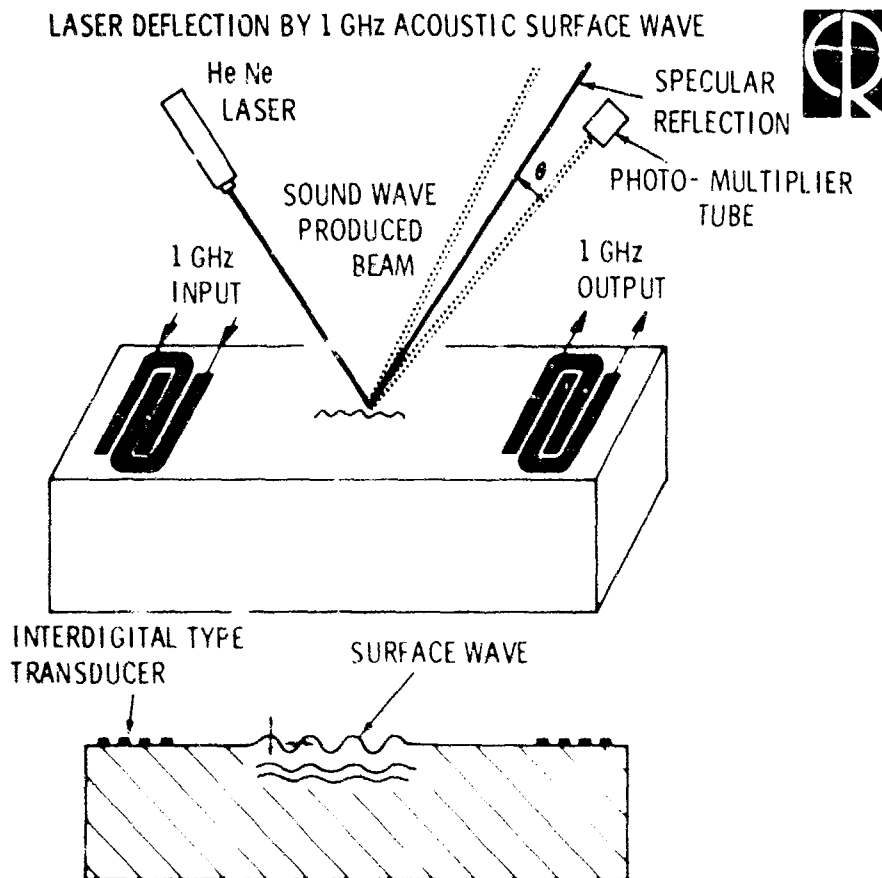


Figure 1. Laser deflection method for measuring acoustic surface-wave (Rayleigh-wave) propagation losses on LiNbO_3 at microwave frequencies.

MICROPROBES FOR MEDICAL ELECTRONICS

The tools required for basic research often lead to technological advance. Such was the history behind the development of an electronic microprobe at the Stanford Electronics Laboratories. The basic research being conducted concerned the measurement of bioelectric potentials in the central nervous system, especially in the brain. For a variety of reasons, the current state-of-the-art in probes for this application was inadequate. Consequently, Professor J. B. Angell and one of his doctoral students, K. D. Wise, under AFOSR sponsorship through the Joint Services Electronics Program, sought to correct this inadequacy, with a resultant significant technological advance in the design and fabrication of microprobes. This important new approach utilizes the fabrication techniques of integrated circuits and microelectronics to deposit and etch layers of materials to build the probes.

The problems of measuring potentials on the cellular level in biological systems arise from the size of the cells involved and the environment in which they exist. A typical neuron is from 10 to 100 microns in diameter, and is immersed in an extracellular fluid somewhat more dilute than present-day sea water. The membrane which defines the cell is more permeable to some ions than to others; the resulting difference in the intra- and extracellular ionic concentrations gives rise to a transmembrane potential of some 70 millivolts. A sufficient stimulus will cause the cell membrane to depolarize, with the result that a nerve impulse is propagated. Ideally, the electrode which couples this biological system to the recording amplifier should be small enough to approach a single cell closely while causing a minimum amount of damage to the surrounding tissue. Electrode-tip diameters should not exceed a few microns. Actually, electrodes used for intracellular recording must have tip diameters of less than one micron.

Microelectrodes in common use today are either metal electrodes or glass micropipettes. The metal electrodes are formed from electrolytically pointed metal wires, and are insulated, except for recording areas at their tips. Glass-pipette electrodes are usually filled with a saline solution so that the cell is contacted through a fluid junction at the electrode tip. However, any ion exchange between the saline solution of the micropipette and the intracellular saline solution can alter the properties of the neuron. Thus, although the pipette electrode is useful for d.c. and low-frequency recording, the metal electrode is generally preferred elsewhere. Unfortunately, the fabrication techniques employed for both types of

conventional electrodes do not permit close control over the physical and electrical characteristics of these electrodes. This is a serious disadvantage in neurological research at the present time.

The Stanford work has been directed at the design and fabrication of single- and multiple-electrode probes which combine high spatial selectivity (small recording area and tip size), reduced electrode impedance, low noise, and wide recording bandwidth. The use of microelectronic-fabrication technology not only permits these demanding requirements to be met, but also allows the electrical and physical characteristics of the microprobes to be closely controlled. These electrodes are common configurations for the multielectrode probes, and interelectrode spacings as small as 10 microns are possible.

In construction, gold electrodes are electroformed on a silicon wafer using photoresist, a photosensitive acid-resistant lacquer, as a plating mask. These electrodes are then insulated by coating them with a thin film of silicon dioxide, which is selectively etched away, using conventional photoresist techniques, to form controlled recording areas at the electrode tips. The silicon carrier is then shaped by chemical etching into a form suitable for insertion into the brain. This procedure requires a well-controlled, low-temperature system for the deposition of the insulating silicon-dioxide film. A system based on the radio-frequency glow-discharge technique, built by R. H. Weissman of Stanford, has been used successfully for this application. Physically, the silicon carrier in its present form consists of a rectangular portion, 0.5 mm wide by 5 mm long, which serves as a mounting base for wires to the recording amplifier, and an additional length of 5 mm over which the carrier width is tapered to a tip diameter of 0.08 mm where the electrode recording areas are located. After the output wires are attached, the silicon carrier is mounted in the end of a glass capillary tube which has an outside diameter of about 1 mm.

NEW TECHNIQUES FOR DERIVING VOICING INFORMATION IN SPEECH PROCESSING

Advanced techniques for processing verbal information in the form of speech give promise of many sophisticated uses in military communications; but they require that signal analyses be based on specific characteristics of the signal rather than on generalities. One of the important characteristics of the speech signal is the source of acoustic energy. For a major portion of the time, this is provided by voicing, i.e., the vibration of the vocal cords, which are set in motion by the flow of air and, in turn, modulate this flow to transform a portion of its energy into sound.

Unfortunately, this process occurs at the back end of the vocal tract where it is most difficult to examine and to measure it. One approach which has been used at AFCL for some time is to photograph the vocal-cord activity with a high-speed camera so that the glottal area can be determined as a function of time. Knowing this, the researcher can utilize a rudimentary theory to transform area to volume velocity of exhaled gas as a function of time. The periodicity and spectrum content of this gas flow describe the actual sound source for voiced speech.

Unfortunately, considerable difficulties have been encountered in reducing data. The glottal area has been determined from a hand tracing of the periphery as seen in a projected image. Human variability, combined with the fact that the edge is not sharply defined when lighted from above, have introduced considerable noise into the reduced data.

Two new techniques have been evolved in AFCL's Data Sciences Laboratory to help alleviate this problem. First, the edge of the glottal area has been sharpened by making the high-speed movies with subglottal illumination, i.e., with light that comes through the anterior tracheal wall below the larynx. No one had done this before, to achieve it, Mr. Henry Soron designed a specially cooled high-intensity light source. Coupled with a fast lens and film combination, the vocal cords are seen in silhouette, and the edges are much more sharply defined. A comparison of the results of using top and subglottal illumination can be seen in Figure 1. It will be noted that light, scattered by the tissue, has reduced the effectiveness of the subglottal illumination in the anterior portion. This is a remaining problem.

Second, Mr. Sheldon Michaels has written a computer program that determines the edge by automatic means. Pertinent parts of the image of the glottal opening contained on one frame are scanned and digitized. Initially, the experimenter sets two segments of one scan line so that one segment spans each of the two glottal edges near the middle of the image. The computer looks for the greatest change in density along each line segment by ascertaining positive and negative peaks in the density derivative. The two points then determined tell the computer where to look in the next line above, and the machine

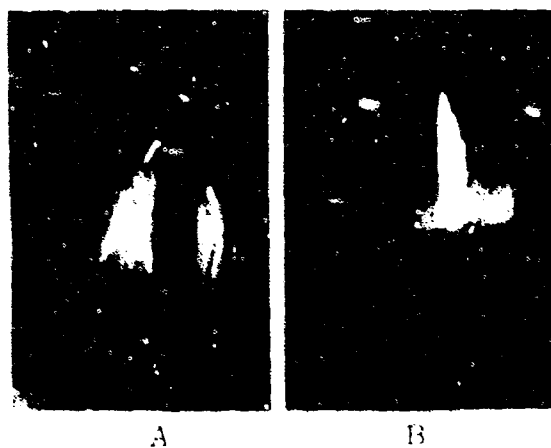


Figure 1. Comparison of glottal illumination methods.
a. Top illumination.
b. Subglottal illumination.

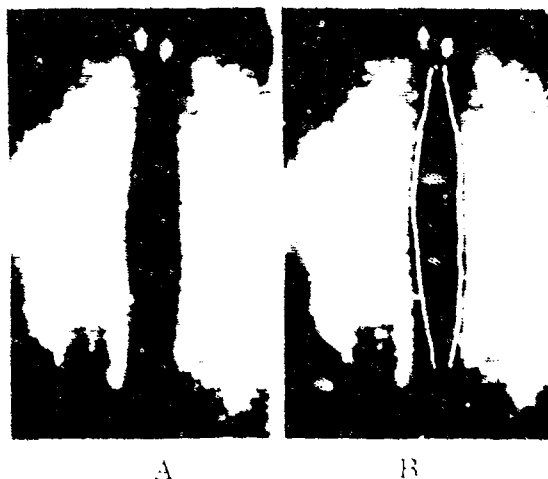


Figure 2. Digitized glottal image.
a. Digitized.
b. Digitized with computer-determined edge.

continues to examine upward, line by line, until the two edges converge. It then returns to its starting point halfway down the image, and moves downward until the two edges again converge. The edge points are smoothed to a realistic contour. Figure 2 shows a fully digitized image alone, and then with the edge

contour determined by the computer superimposed upon it.

A better understanding of voicing resulting from such studies can be expected to contribute to improved signal processing in military communication systems.

electronics

THE PHOTON ECHO

The typical photon-echo experiment presents a striking effect. A thin ruby crystal is illuminated by two successive intense short pulses of coherent light, t seconds apart, obtained from a ruby-laser source. As expected, the crystal will transmit the two pulses t seconds apart. But then one observes a curious additional feature: a third light pulse emerges spontaneously from the crystal about t seconds following the second pulse, and still relatively intense. The resemblance of the third pulse to an echo explains the echo nomenclature.

Figure 1 is a schematic of the two-pulse input and the three-pulse output. The effect* was first observed by Abella, Kurnit and Hartmann at the Columbia Radiation Laboratory, Columbia University. (1)

A clue as to the underlying mechanism of the photon echo can be obtained by considering incoherent illumination instead of coherent illumination of the crystal. In the former case, the crystal would radiate weakly and continuously, once the pulse of illumination is turned off, with no discrete, intense bursts of radiation. This implies that the salient, individual crystal atoms involved in emitting the packets of light emanate the packets at different times, i.e., independently. On the other hand, the intense burst of light implies that the atoms are

cooperating and emitting the bursts as an integrated unit. Thus, a prerequisite for the photon echo is the attainment of coherency in the states of the atoms within the ruby. Such states were first studied by Dicke. (2) It is to be observed that the coherent light establishing the cooperative states of the atoms also implies cooperativeness within itself, so that "coherence begets coherence." It was the advent of the laser which brought into existence intense coherent light sources and so made the photon echo feasible.

To complete the mechanism, all that remains is to incorporate the timing of the echo pulses. This is obtained by properly alternating, in time with the coherent light pulses, a relaxing force to nullify the former's cooperative action. Such a divisive force is found in the electrostatic field between the atoms of the crystal. This field undermines the integrating action of the coherent pulses because the salient atoms involved in emitting the output pulses are randomly distributed among the crystal sites so that the field is different for each of these atoms.

An anticipated application of the controlled pulses of the photon echo is to computer technology and associated memory devices employing light. The basic advantages of the photon echo include a built-in reliability control, and speeds of the order of 10 nanoseconds. In fact, memory devices have previously been studied for the spin echo, an echo phenomenon similar to the photon echo in the radio-frequency range. (3)

*This work was supported by the Joint Services Electronics Program, Air Force Office of Scientific Research (OAR), Army Research Office, and Office of Naval Research.

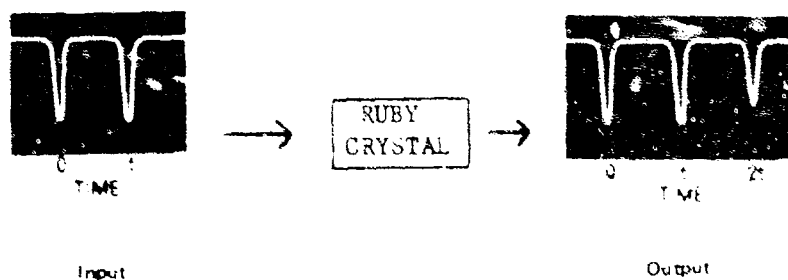


Figure 1. Schematic of pulses in photon-echo experiment.

DISCRETE TARGET-IMAGING PROPERTIES OF HIGH-RESOLUTION RADAR SYSTEMS

In the years since World War II, coherent radar system performance has been significantly improved by the development of sophisticated signaling waveforms and received signal-processing techniques. These techniques achieve synthetic-range and cross-range resolution capabilities which far surpass the resolution capabilities of the physical radar system itself.

It is important to realize that, as the synthetic resolution cell of a system becomes smaller than the dimensions of the actual radar target, the spatial and frequency-dependent properties of the target's electromagnetic scattering become fundamentally important. Indeed, the radar system itself becomes an imaging device which transforms the electromagnetic scattering properties of the target into a display for the radar observer.

If we are to understand the nature of the observed system output, it is essential that we determine those electromagnetic properties of the target which are imaged and the manner in which the radar itself distorts these properties.

The discrete target-imaging properties of several classes of coherent radar systems are being studied by Dr. John K. Schindler of AFRL's Microwave Physics Laboratory. The studies are being made from the viewpoint of interpreting the images produced by several classes of radar targets.

The coherent range-Doppler radar forms an important class of high-resolution systems. Adjacent point targets are resolved in the system output by their differing range and closing velocities. The ability of the radar to resolve adjacent targets is described completely by the system's wideband ambiguity

function. Primarily dependent upon the transmitted waveform and the received signal processing, the ambiguity function is usually well known to the radar-system designer.

In Dr. Schindler's studies the system ambiguity function plays a fundamental role in developing the range image of any nonrotating discrete target. Conceptually, the range image is generated by passing the electromagnetic temporal impulse response of the target through a conventional linear system. In a real system, the temporal output of the system is the observable image of the target, and the image distortion introduced by the linear system is due to the radar itself.

The temporal impulse response of a target is a function of the target's shape, size, material composition and spatial orientation with respect to the radar. It is theoretically calculable for a large class of shapes, and experimental techniques exist for approximating its form. Indeed, a wealth of essential information already exists on the wideband response of radar targets.

Thus, the range-imaging properties of discrete targets have been found to be completely characterized by two well-known quantities: the radar-system wideband ambiguity function, and the target's electromagnetic impulse response. Investigations of the range-imaging properties of targets will yield new insight for interpreting target images, and provide new criteria for the design of radar-signaling waveforms. Investigations of the discrete target-imaging properties of systems with cross-range resolution such as the synthetic aperture radar are presently underway, and promise to yield still further insight into the imaging capabilities of high-resolution systems.

ELECTROMAGNETIC-WAVE PROPAGATION

The theory of special relativity has been known for some 50 years, but its application to problems involving moving media is relatively new. Dr. Charles H. Papas of the California Institute of Technology, under the sponsorship of AFOSR, is a recognized pioneer in solving problems in which electromagnetic-energy propagation is affected by the characteristics and motion of the medium.

Dr. Papas has created the methodology necessary

to describe the scattering of electromagnetic waves by inhomogeneous bodies, (a problem that could not be treated previously), by extending the method of invariant imbedding to include two- and three-dimensional inhomogeneities. This method can be used to compute the radar cross section of meteor trails, ball lightning, re-entry vehicle wakes, and focusing problems of Luneberg lenses involving moving media. Other relativity problems treated include

the scattering of radar energy from both a jet stream and the plasma sphere of a nuclear detonation.

Preliminary studies of clear-air-turbulence radar-reflectivity theory have established that the theory is limited to situations where the Born approximation is valid. Work on this problem is in progress.

Dr. Papas has also defined the exact dipole field for an orbiting transmitting antenna carried by an

artificial satellite. This description is pertinent to earth satellites as well as to space probes.

The research accomplished by Dr. Papas provides the theoretical understanding and the computational tools necessary for an accurate analysis of operational problems related to airborne and ground radars, interplanetary communications, and satellite communication and control.

electronics

WIDE-BAND SCATTERING FROM RANDOMLY DISPERSED OBJECTS

The nature of the scintillation (fluctuations of intensity with time) of electromagnetic waves reflected from randomly dispersed scatterers depends critically upon their signal bandwidth. Physical situations in which this scintillation is important include atmospheric and ionospheric propagation of wide-band radio and radar signals, the scattering of light by aerosols and hydrosols, and microwave transmission in waveguides with random perturbations. Although several experiments have been conducted on the difference in scattering between laser (narrow-band) and ordinary (wide-band) light at optical wavelengths, the results are inconclusive, and cannot be readily applied to the radar case.

Mr. Walter Rotman of AFRL's Microwave Physics Laboratory, in studying this scattering problem, selected a simple one-dimensional model (Figure 1) for analysis. The model consists of a series of randomly placed discontinuities on a coaxial microwave transmission line. The parameter of interest is the fluctuation of the reflected power at the input to the transmission line for differing positions of the scatterers, as the bandwidth of the input signal is

changed. Mr. Rotman's theory, which has been confirmed by transmission-line experiments, indicates that the fluctuations of the reflected energy for different sets of scatterers is much less for wide-band, than for narrow-band, signals. Furthermore, the wide-band signal may be replaced, for purposes of analysis, by a signal composed of a series of discrete equispaced frequencies, where the frequency interval is selected so that their responses are statistically independent of each other. This latter result, which is reminiscent of the sampling theory in the time domain, leads to considerable simplification of the mathematical analysis.

The general methods which were developed can also be applied to a variety of other optical and radar problems, such as three-dimensional distributions of moving or stationary random scatterers, the correlation of the reflected signal at physically separated points in space, and bistatic (angular separation of transmitter and receiver) geometries. These results will be evaluated by further laboratory experiments in which randomly dispersed metal spheres are illuminated by microwave fields, and will be applied

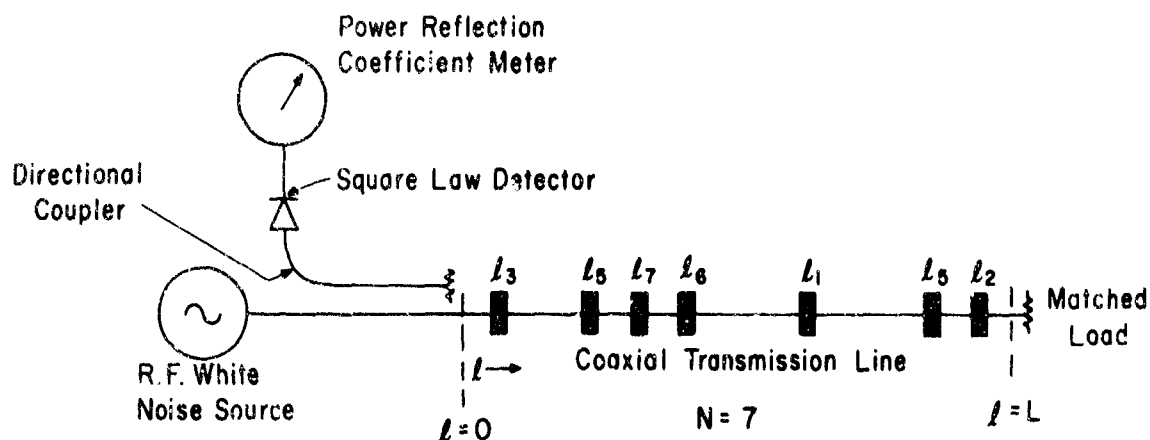


Figure 1. Wide-band microwave experiment on reflections from randomly dispersed discontinuities in a transmission line.

to recent data on tropospheric scattering obtained at millimeter wavelengths.

The study shows that the scintillation of light in optical scattering experiments occurs at a very rapid rate, on the order of the time required for a particle to move a distance of one wavelength of light.

Conventional measurements would, therefore, show no difference between laser and ordinary light, since the usual optical detectors do not respond rapidly enough to observe the fluctuations. However, these effects should be readily detectable with high-speed detectors having submicrosecond response times.

materials research

HIGH-TEMPERATURE OXIDATION OF AIR FORCE MATERIALS

Supersonic aircraft and re-entry-type space vehicles require, on leading-edge surfaces, materials capable of withstanding extremely high temperatures under oxidizing conditions. Certain of the boride compounds are being investigated by AFSC's Air Force Materials Laboratory for use in this application. One of the more promising of these, at the present time, is zirconium diboride with additions of silicon carbide.

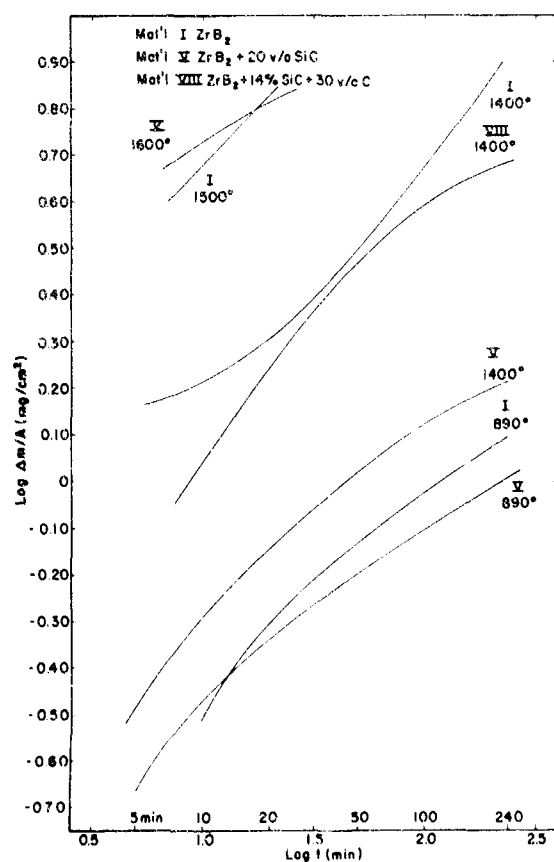


Figure 1. Relative oxidation rates of 3 boride compounds at 250 torr oxygen pressure.

Dr. Henry C. Graham and his associates at ARL's Metallurgy and Ceramics Research Laboratory have been studying the oxidation properties of these boride materials. Three such materials have been investigated to determine the conditions best suited for their application: material I—zirconium diboride with no additives; material V—zirconium diboride with 20 percent by volume of silicon carbide; and material VIII—zirconium diboride with 14 percent of silicon carbide and 30 percent of carbon.

Weight-change measurements as a function of temperature at an oxygen pressure of 250 torr, over the temperature range of 800°C to 1600°C, have been made on each material. Figure I shows some of these data. Below 1300°C there are no significant differences in the behavior of the three materials. However, above this temperature, material V shows superior oxidation-resistant properties. Material I oxidizes very rapidly at 1500°C and above.

Oxidation studies on materials that form volatile oxidation products are difficult to interpret by weight-change measurements alone. However, weight-change measurements are necessary in most cases to indicate under what conditions the volatile products form.

Figure II shows weight-change measurements on material V. These measurements indicate the changes in the mechanisms involved. At 1300°C, after about 6 hours, the rate of weight gain levels off, and then actually shows a weight loss as the volatile product forms at a faster rate than the adherent oxide. The rate of weight change at 1400°C is relatively low, while at 1200°C the rate is highest. A very viscous layer of silicon oxide is formed on this material at 1200°C, and it effectively retards the vaporization or formation of boron oxide. Possibly the boron reacts with the silicon oxide to form a borosilicate glass.

The equipment developed by Dr. Graham's group (1) to study the oxidation of high-temperature materials such as these diboride compounds will permit measurements of this type to be made up to 2500°C. This will contribute to the evaluation and development of new materials to meet the future needs of the Air Force.

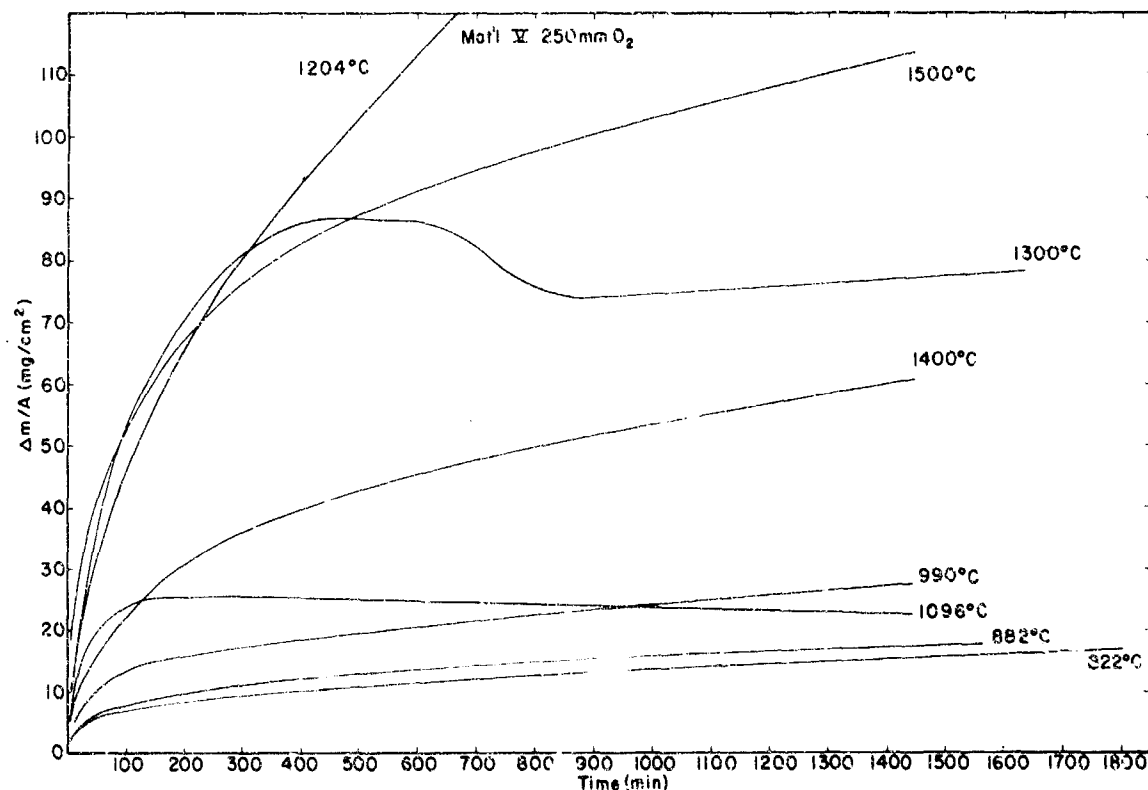


Figure 2. Oxidation of material V-ZrB₂ + 20 vol% SiC at 250 torr oxygen pressure.

materials research

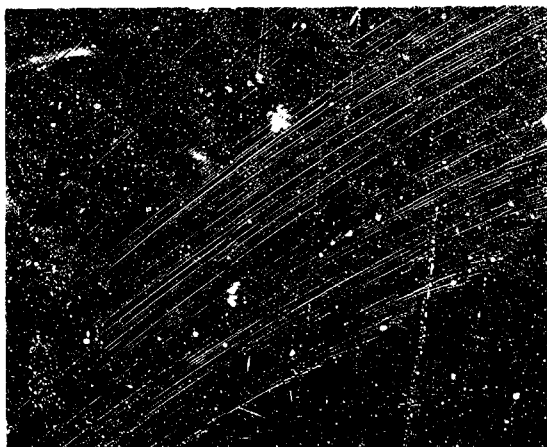
REFINEMENT OF AUSTENITIC GRAIN SIZE IN 18% Ni MARAGING STEELS BY THERMAL TREATMENT

Maraging steels frequently contain small volumes of material in which chemical segregation has occurred. In some cases this segregation has been found to cause an impairment in mechanical properties. Segregation can usually be removed by a long, high-temperature annealing treatment; but annealing in this fashion causes undesirable grain growth. Although it is commonly held (1, 2) that grain size in maraging steel can be controlled only by thermo-mechanical processing, a joint study by Mr. J. A. Roberson of ARL's Metallurgical and Ceramics Research Laboratory and Messrs. G. Saul and A. M. Adair of AFSC's Air Force Materials Laboratory has shown that this control can be achieved by thermal treatment alone. These results offer possibilities for improvements in present commercial practices.

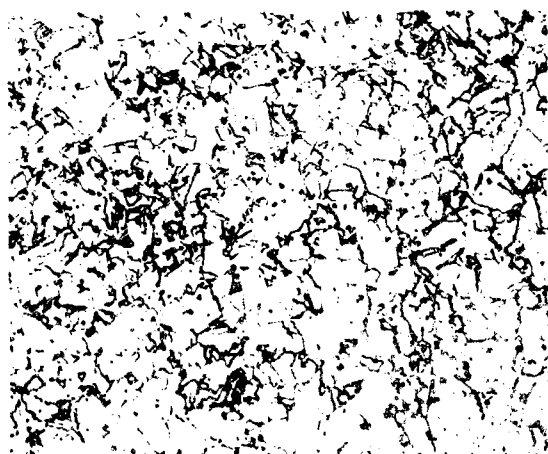
This new technique, which has been developed for controlling the austenitic grain size of 18% Ni

maraging steels by thermal treatment alone, has been applied to two different grades (250 and 300, of maraging steel. A large-grain size (ASTM 2) was reduced to ASTM 7 in both cases. The process of grain-size refinement requires thermal cycling from a temperature below the martensite transformation range to a temperature considerably above the austenitizing temperature. The minimum austenitic grain size attainable depends on the prior strain in the material as well as on the thermal treatment. In the absence of prior cold work, the mechanism of recrystallization evidently requires the plastic strain generated by the martensitic transformations during thermal cycling. While significant grain-size refinement can be attained by one cycle to the proper temperature, the attainment of the minimum uniform grain size requires several cycles.

The effects of austenitic grain size on tensile



Homogenized at
2000°F 15 hours
ASTM Grain Size No. 1
133X



Grain Size Refined by
Thermal Cycling to
1700°F 5 cycles
ASTM Grain Size No. 7-8
266X

18 % Ni - 250 Grade Maraging Steel

Figure 1. Grain sizes resulting from a homogenization treatment and a refinement treatment.

properties have been investigated both at room temperature and at elevated temperatures. It has been found that the prior austenitic grain size has a small but significant effect on the mechanical behavior of aged material at room temperature. The effects of grain size in the austenitic temperature region are more significant. Tensile properties are about the same for similar grain sizes whether obtained by thermal cycling or by thermomechanical processing. The grain sizes resulting from a homogenization treatment and a refinement treatment are shown in Figure 1. The effects of prior austenitic grain size on flow stress are shown in Figure 2. The data points marked Tc1 and Tc6 represent specimens in which the grain size was reduced by thermal cycling after the homogenization treatment.

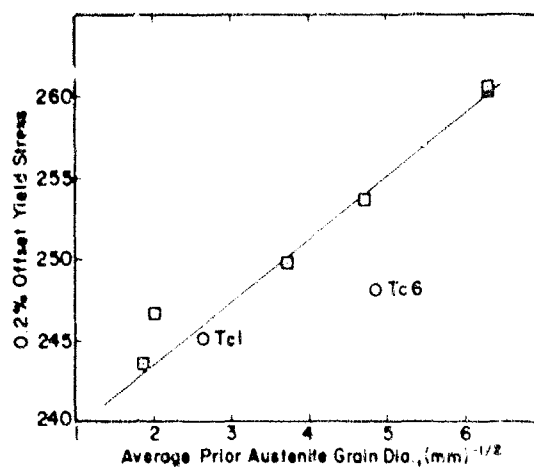


Figure 2. The effects of prior austenitic grain size on flow stress.

SURFACE ENRICHMENT IN Fe-Ni ALLOYS

The problem of stress corrosion cracking is one of the most serious materials problems in the Air Force today. This problem pervades the entire structural materials spectrum, from the stainless steels to the aluminum alloys. One of the most interesting theories of stress corrosion cracking depends for its validity on an initial enrichment step. During this step, atoms of the more active element(s) in an alloy preferentially dissolve, leaving behind an ennobled surface of the less active atomic species. In order to test this theory, it is necessary to determine the

dissolution behavior of metals and alloys in a very quantitative manner. Pickering (1,2,3) has used a very sensitive electrochemical technique to determine the dissolution behavior of Cu-Au and Cu-Zn alloys. However, such a technique is not possible in stainless steels since the equilibrium potentials of the components of the Fe-Cr-Ni system all lie below the H^+/H_2 equilibrium potential in acid solution.

The existence of this enrichment phenomenon has been demonstrated in Fe-Ni alloys by Lt. Dale O. Condit of ARL in his probing investigation of the

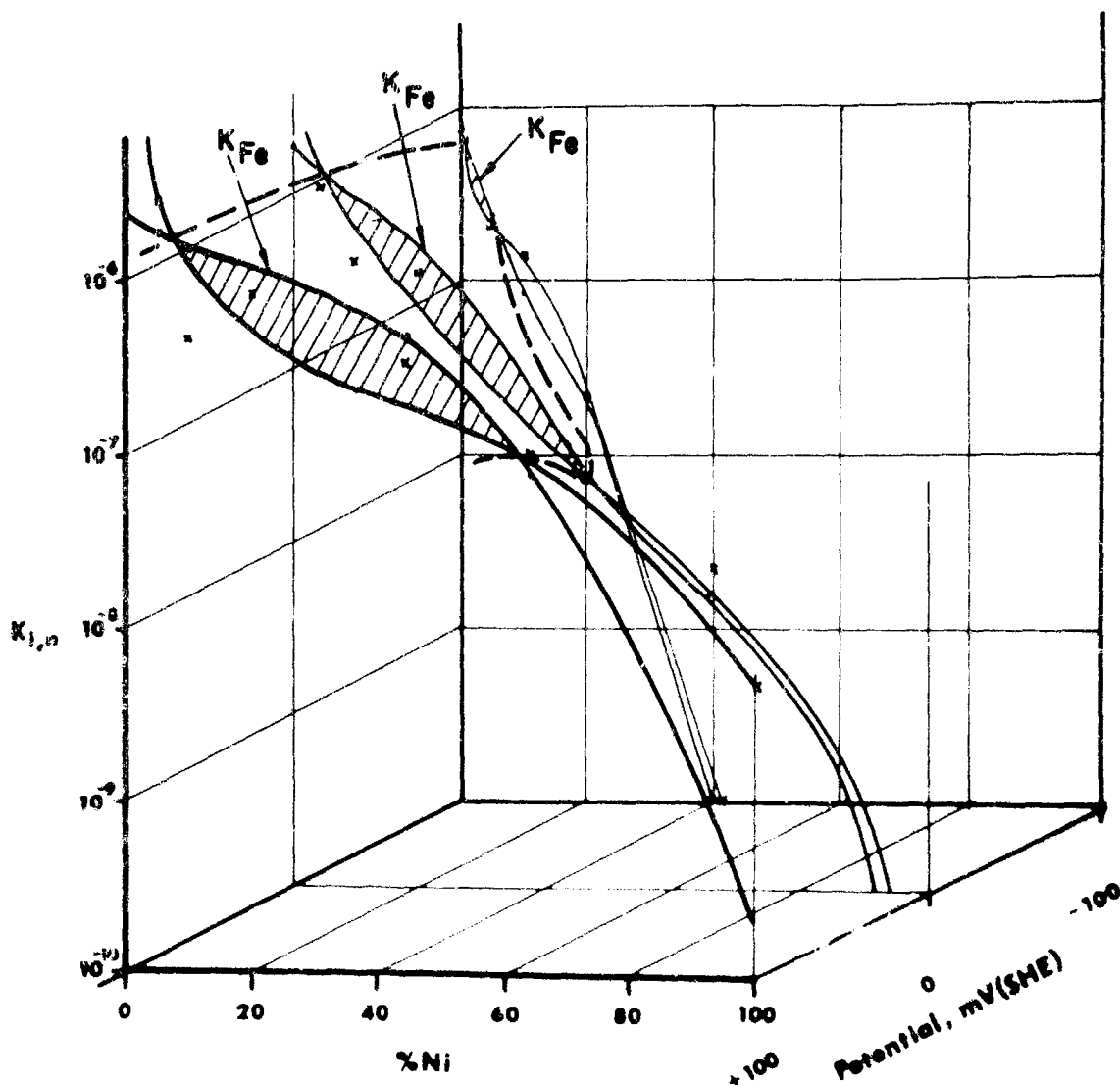


Figure 1. Intrinsic rate constants for Fe and for Ni in 1N H_2SO_4 as a function of Ni composition and potential. (shaded areas indicate regions of Ni enrichment)

dissolution characteristics of alloys in this system. Five Fe-Ni binary alloys, pure Fe, and pure Ni were dissolved electrochemically in a 1N H₂SO₄ solution at various potentials. At selected times during the potentiostatic dissolution, samples of the acid solution were removed from the test cell and were analyzed using an atomic absorption spectrometer to determine the concentrations of Fe and Ni present.

Using these concentrations, anodic polarization curves were determined. These curves indicated that the dissolution of the alloys may be structure-dependent, with face-centered cubic Fe-Ni alloys having lower corrosion currents than body-centered cubic alloys.

Each Fe and Ni concentration was found to obey a dissolution rate law that:

$$C_i = a_i t^{n_i} \quad (1)$$

where C_i was the concentration of Fe or Ni in solution, a_i was a constant, t was time, and n_i was the slope of the logarithmic equation. This equation was used to determine an intrinsic rate constant for Fe and Ni as a function of Ni composition at constant potential, E . This rate constant was normalized by dividing each calculated rate constant by the respective composition of Fe or Ni in the alloy being dissolved. The normalized rate constant was thus given by:

$$K_{i,n} = \frac{M_s}{AM_i N_i} \left(\frac{dc_i}{dt} \right)_E \times 10^6 \quad (2)$$

where M_s was the mass of the solution in grams; A , the area of the specimen; M_i , the molecular weight of Fe or Ni; and N_i , the atomic percentage of Fe or Ni in the alloy being dissolved. $K_{i,n}$ is then given in moles/cm²·sec.

The value of n_i was approximately 1.0 for pure Fe and for Fe and Ni in the alloys; and n_i was approximately 0.7 for pure Ni. As a first approximation, n_i was assumed to be 1.0, and the values for $K_{Fe,n}$ and $K_{Ni,n}$ were determined at three potentials of dissolution: -100mV, 0mV, and +100mV(SHE). The results of these calculations are shown in Figure 1. The shaded areas at each potential indicate the range of compositions where the rate of Fe dissolution exceeds the rate of Ni dissolution, that is, where Ni enrichment could be expected. The figure indicates that the probability for Ni enrichment increases with potential in the range of low Ni compositions.

The enrichment theory advanced for the mechanism of stress corrosion cracking is supported by the data obtained in this study. The results of Lt. Condit's investigation also indicate that this enrichment process may be active in other systems, and that studies in other aerospace alloy systems, specifically the Al-Ti alloys, should be undertaken.

materials research

THERMALLY STIMULATED PHOTOELECTRONIC PROCESSES

There are a great number of nonmetallic materials which, when irradiated with light, X or gamma rays, or charged particles while at a low temperature, will store part of the incident energy through the trapping of electronic charge in metastable states. Upon subsequent heating, the electrons or holes from various traps are released in temperature ranges characteristic of the traps. If the charge passes through a mobile state upon being released, it may be detected by measuring a current when a constant voltage is applied to the material. This is called a thermally stimulated current (TSC). In some cases the released charge has sufficient energy to escape the material, and is observed as thermally stimulated exoemission (TSE). If the charge proceeds to a lower energy state with the emission of light, then the material is said to thermoluminesce (TL). In many cases the resultant thermally stimulated process is proportional to the integrated incident energy.

This phenomenon has various applications to radiation dosimetry. The processes are also useful to the understanding of the materials themselves, in that

the defects which give rise to trapping, the emission of light, etc. can be characterized and identified, and eventually associated with other defect-controlled phenomena such as ionic diffusion or conductivity as well as the more directly related constant-temperature photoelectronic properties.

ARL work done in-house and under contract has included both the theoretical and experimental aspects relevant to the utilization of the phenomena. Here a part of the theoretical work is discussed.

Thermally stimulated phenomena are most often recorded while the temperature is changed at a constant rate. The resultant curves frequently show a series of peaks in luminescence, current or exoemission. The portion of a curve in the neighborhood of a peak is called a "glow curve." If the electronic transitions are of the same kind throughout a glow curve, then the curve shape and position can be used to calculate the thermal-activation energy, E , for the trapped charge and a frequency factor, ϕ . If the kinds of electronic transitions change within a glow peak, it is still possible to calculate E from the initial portion

of the glow curve.

There are two classical analytical forms applicable to models used in the analysis of glow curves. These are the monomolecular form:

$$I(T) \propto m \phi \exp [-E/kT - \phi h(T)], \quad (1)$$

and bimolecular form

$$I(T) \propto m \phi \exp[-E/kT] / [1 + \phi h(T)]^2, \quad (2)$$

where $I(T)$ is the thermally stimulated response versus the absolute temperature, T ; m is the trapped charge density; E is the trapped activation energy; k is Boltzman's constant, and

$$h(T) \equiv \int_0^\infty dT \exp(-E/kT)/\beta,$$

where β is the heating rate.

Calculations by Dr. Peter L. Land of ARL's Metallurgy and Ceramics Research Laboratory show that the bimolecular form as written above is applicable only to TL. A related expression applicable to TSC and TSE is:

$$\sigma(T) \propto m \phi \exp[-E/kT] / [1 + \phi h(T)]. \quad (3)$$

Evaluation of experimental glow curves by the above formulas can utilize the fact that the initial growth of curves (the first five percent) is described by $n \phi \exp(E/kt)$. It is shown, however, that results may be improved, and without undue inconvenience, if an analysis based on the complete expressions 1, 2, or 3 is used.

Equations 1 and 2 have been converted to simple approximate equations (which can be in error by 10 percent) giving E and ϕ in terms of the temperature of maximum response, T_m , and the temperatures, $T_{1/2}$,

where the curve amplitude is one half the maximum. Dr. Land has derived equally simple, but exact, expressions from equations 1, 2 and 3 which utilize the inflection points of glow curves together with T_m for calculations of E and ϕ .

Dr. Land has discussed three basic models which yield the analytical glow curves 1, 2 and 3. For those cases where electronic transitions are localized at sites of a single species, there is no TSC or TSE; the TL is always described by the monomolecular form, Equation 1, with a specific energy and specific frequency factor. In those cases where a charge passes through a band state which is native to a material or is impurity-induced, the TL may be described by Equations 1 or 2, while the TSC and TSE may be described by Equations 1 or 3. In the third model an electronic charge is transferred via overlapping states associated with separate defects. It is shown that at high defect densities this model reduces to a band model, while at low densities it reduces to the localized model.

When Equations 1, 2 or 3 apply, the parameter, ϕ , depends parametrically on the defect densities, the electronic transition rates and the distribution of electrons prior to the occurrence of a specific glow peak. The several specific forms ϕ takes are presented and discussed. For some conditions the glow curves are not described by a simple analytical form because, in effect, ϕ changes throughout the glow curve. It is shown, however, that this nonanalytical behavior is not expected to occur frequently, and that, where it does occur, the control one has over the "initial" electron distribution will frequently permit a systematic approach to conditions which will yield analytical glow curves. A comparison of the changes in the TL and TSC glow-curve shape and position resulting from changes in the "initial" charge configuration, in both the region of nonanalytical and analytical behavior, demonstrates the value of making simultaneous TL and TSC measurements whenever possible.

mechanics

RADIATIVE GAS DYNAMICS

It has been recognized for some time that radiative heat transfer must be included in analyses of superorbital reentry. However, despite the numerous investigations performed, existing solutions are either simplified to the point of being unrealistic, or so complicated that very little physical insight can be derived. Thus, research to provide simple, yet realistic approximations to the physical complexities of general situations in radiating, flowing gases (1,2) has been conducted first at MIT and then at FJSRL by Capt. David Finkleman.

The transport of photons, radiative transfer, is much the same as that of material particles. The equation governing their motion involves the geometrical relations between the direction of the propagation vector and the coordinate axes, as well as the quantum mechanical relations among the various radiative processes and the emission of thermal radiation which they lead to. Although photons of each frequency of interest require a monochromatic transfer equation, only integrated quantities (heat flux, energy density, etc.) are of aerodynamic inter-

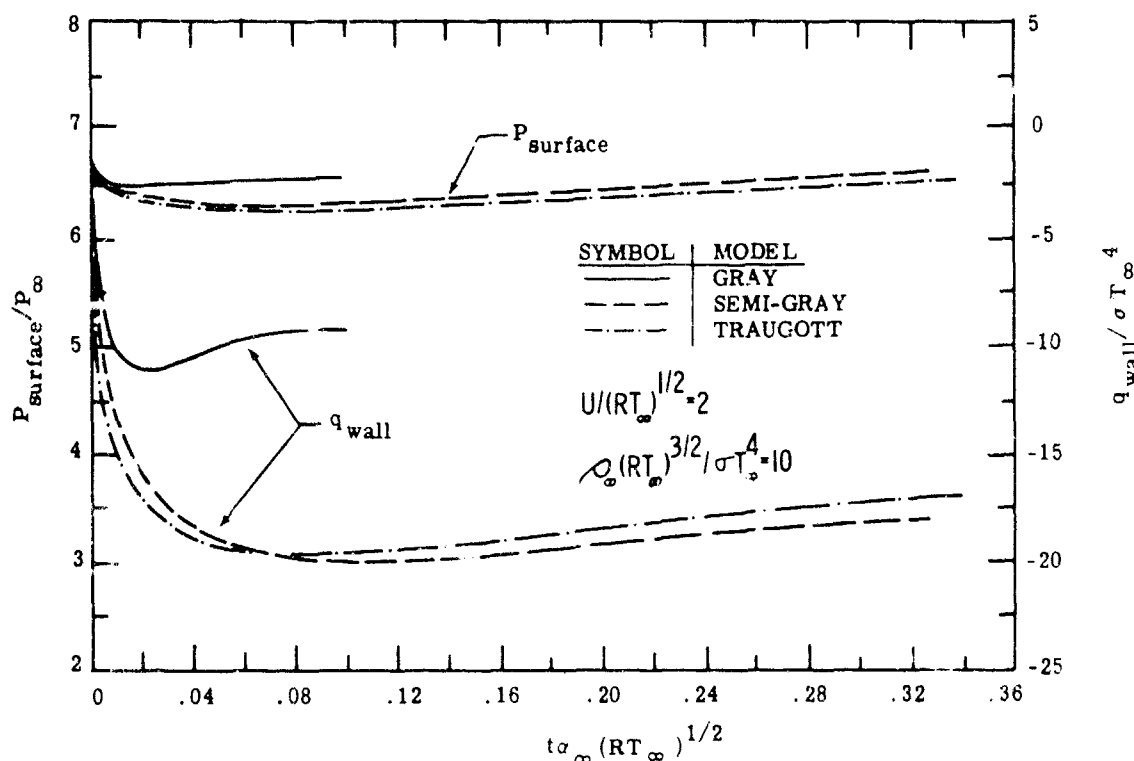


Figure 1. Surface pressure and wall heat flux for a planar piston in uniform motion. (upstream absorption included)

est. However, there are severe computational and physical consequences if all radiative processes considered important are considered separately. In addition, even the monochromatic transfer equation possesses a convenient, closed-form general solution only in a planar geometry. Even one-dimensional spherically or cylindrically symmetric media are difficult to handle; multidimensional situations are presently untractable.

To alleviate the physical difficulties, a simple model of nongray gases (media which absorb each frequency to a different extent) was devised. Since only integrated quantities are of interest, the approximation is specifically intended to improve the prediction of radiative heat fluxes. Appropriate intensity-averaged absorption coefficients may be defined and, although their strict determination depends upon the solution of the problem in question, approximations may be inferred from well-known asymptotic expressions in transparent and opaque media. If these averaged absorption properties are postulated to be independent of geometry (i.e., isotropic), it follows that they depend only upon the Planck and Ross-

eland mean absorption coefficients, which are well-known properties of any gas. If the ratio of these two properties depends only upon temperature, very simple expressions result. Fortunately, this is often the case for physical problems of practical interest.

The governing isotropic assumption was verified, and it was demonstrated that the approximation is quite good in planar situations. Both heat fluxes and energy densities are predicted accurately in gases whose spectra may be simulated by discrete frequency steps. The model having been verified, it was then applied to the characteristics calculation of piston-induced radiating flows.(3) Figure 1 is representative of the effects which inclusion of spectral effects may have upon radiating flows. Both surface pressure and heat-flux variations are presented. Note that heating loads may be underpredicted by a factor of two if one relies upon a gray gas (one which absorbs all frequencies to the same extent). The analysis may be interpreted in terms of the hypersonic flight of slender bodies, the case presented representing flight of a 3° half-angle wedge at Mach 20 and at an altitude of 100,000 feet.

LOW-DENSITY SUPERSONIC COMBUSTION RESEARCH

Investigations of supersonic combustion have been made in various laboratories at combustion-chamber static pressures of one half atmosphere and higher. Much of this experimental data has been concerned with shock-induced combustion, or combustion initiated by artificial means such as sparks and pilot flames. Two aspects of supersonic combustion which have received much less attention experimentally are diffusive mixing at low density (pressures of 1 - 3 psia), and autoignition. Such low-density conditions are expected to occur in the combustion chamber of a scramjet engine operating in the high-Mach-number, high-altitude flight regime. The key component of a scramjet-type engine is felt to be the combustion chamber. The processes taking place in the chamber include turbulent mixing and the combustion of injected fuel with a supersonic air stream. A basic understanding of the nature of the combustor problem is considered to be paramount in determining the feasibility of employing supersonic combustion in this type propulsive system.

Low-density diffusive mixing, autoignition, and other aspects of supersonic combustion have been under investigation by Dr. R. G. Dunn, Capt (Dr.) J. E. Drewry and Mr. N. E. Scaggs of the Fluid Dynamics Facilities Research Laboratory, ARL for sometime, utilizing a continuous-flow facility developed at ARL. This facility (Figures 1 and 2) produces concentric streams of air and hydrogen, with the fuel being injected at sonic velocity into the center of the supersonic air stream. As an aid in the design of the combustion chamber, and to provide theoretical predictions of results to be expected in the experiments, a numerical analysis of the combustion-chamber flow field was made on an IBM 7094

computer. Then a parametric study was conducted of supersonic combustion in the diffusive hydrogen-air flow field at air Mach numbers from 1.5 to 2.5, and at static pressures from 1 to 3 psia.

In the experimental phase, approximately 50 channels of data (pressures, temperatures, concentration, and photocell and spectrometer data) are recorded and processed by the data-acquisition system. Interpretation of the experimental data obtained so far is somewhat more qualitative than quantitative. However, the results to date have conclusively established the occurrence of sustained supersonic combustion in the diffusive hydrogen-air flow field at combustor-entrance static pressures near 2.5 psia, for periods ranging up to 20 seconds. Much testing still remains to be done, and diagnostic techniques must be improved and developed. However, the results obtained so far, both numerical and experimental, have been very helpful in indicating the directions to be taken in the effort to achieve adequate laboratory simulation of supersonic combustion for high-altitude, high-Mach-number flight conditions.

Data obtained at ARL in this study are felt to be of fundamental importance in applications for scramjet engines, or supersonic-combustion ramjets. Such engines have a potential for future applications in hypersonic-cruise aircraft and in recoverable boosters for spacecraft launchings. The unique, long-duration capabilities of the ARL facility may eliminate or sharply reduce the requirement for costly flight testing as a means for obtaining basic data applicable to the higher flight Mach numbers.

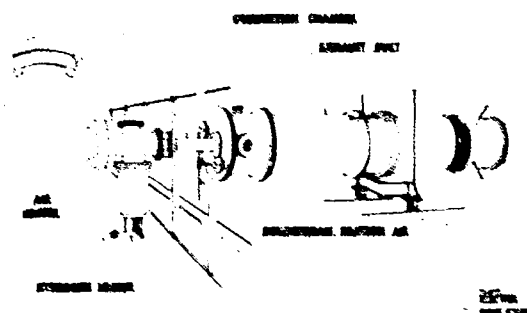


Figure 1. ARL supersonic combustion facility with modified exhaust duct and Mach 1.5 combustion chamber.

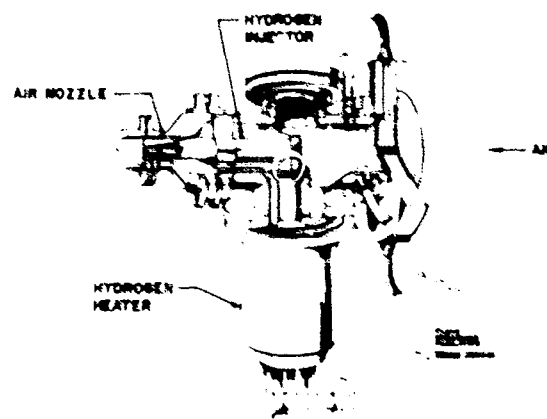


Figure 2. Air nozzle and hydrogen heater and injector.

UNSTEADY GAS-DYNAMICS PROBLEMS RELATED TO FLIGHT VEHICLES

The prediction of unsteady and steady aerodynamic forces on wings and bodies in high-speed flight continues to be of great importance in the design of military air vehicles, and in the solution of problems which arise during their testing and operation. In response to this need, the Mechanics Division of AFOSR (OAR) supports the research of Professor Holt Ashley (formerly of MIT) and his colleagues at Stanford University. In the past two years, his attention has been focused on two problems of current practical importance: wings with control surfaces and other discontinuities at subsonic speeds, and the influence of thickness and other nonlinearities on the loading of thick supersonic lifting surfaces in three dimensions.

In a report(1) on the control-surface work, detailed procedures were described for the numerical calculation of lifting-pressure distribution on a wing or tail with control surfaces or other discontinuities, oscillating in a subsonic main stream. The basis of the solution was the integral equation of a pressure doublet sheet, linearized under the hypothesis of small disturbances. The key discovery permitting a new approach to this problem was Landahl's theorem,(2) which showed that the magnitude of the pressure singularity along a discontinuity line, such as a control leading or side edge, is directly related to the upwash discontinuity at that edge. Two known

exact solutions were shown to verify Landahl's result. The symmetrical motion of a pair of symmetrically disposed trailing-edge controls with rectilinear, swept leading edges was described. Since the publication of that report, further progress has been made, for example, in determining the complete solutions for control surfaces whose hingelines intersect the wing-tip. It is believed that these results will render the process of calculating control-affected airloads (e.g., hinge moments) both more accurate and more efficient. Special fallout is expected from this work with regard to steady-state control-surface derivatives, the calculation of which, in the past, has generally been regarded as a "black art."

Dr. J. J. Kacprzynski's study(3) on the influence of wing thickness on unsteady, three-dimensional supersonic airloads (e.g., lift) shows that the nonlinear lift differs insignificantly from the linear one, but that the aerodynamic center moves significantly forward. He numerically calculated 5% and 10% thickness effects on a 45° delta wing, and found a substantial difference between the linear and nonlinear lifting potential distributions. From work done to date, quantitative confirmation has been furnished for the conclusion that there can often be important nonlinear effects on the unsteady loading and flutter of three-dimensional lifting surfaces in supersonic flight.

SUPERSONIC COMPRESSOR RESEARCH

Axial compressors are employed in many Air Force applications including the majority of aircraft engines, numerous types of ground-support equipment, and some environmental control systems. Supersonic compressors offer a potential for reducing the size, weight, and cost of these components.

When operating supersonically, an axial compressor is potentially capable of producing at least twice the stage-pressure ratio of a modern transonic design. Alternatively, one supersonic stage can produce a pressure ratio equal to a series of many subsonic stages. However, the current state-of-the-art does not permit it to compete in terms of efficiency.

Before a supersonic compressor can become a practical reality, ways must be found to raise its thermodynamic efficiency to a level roughly comparable with current transonic designs. This is the broad objective of the ARL supersonic-compressor-research program.

In the following figures some recent research results are presented which cover various facets of the overall program. Figure 1 shows the evolution of performance achieved with one experimental rotor from the joint effort of ARL and AFSC's Arnold Engineering Development Center (AEDC). In all three cases, the same rotor blades were used without

modification; only the casing contour was changed and the tips of the blades machined to match. This example illustrates some of the things which can be accomplished with inexpensive minor modifications to a limited number of test rotors, and typifies the approach followed by this program. Although the three configurations shown would not represent an optimum design, a lot of useful information has been obtained at low cost.

The performance of the most recent rotor tested under the joint ARL-AEOL program is shown in Figure 2. This one, designed prior to the experiments just mentioned, also employs an annulus of constant area. However, a significantly different blade twist distribution and larger hydraulic diameter distinguish it from those tested earlier. The design-speed performance shown here is the best achieved so far in this test series, and represents an improvement of about 10 percent.

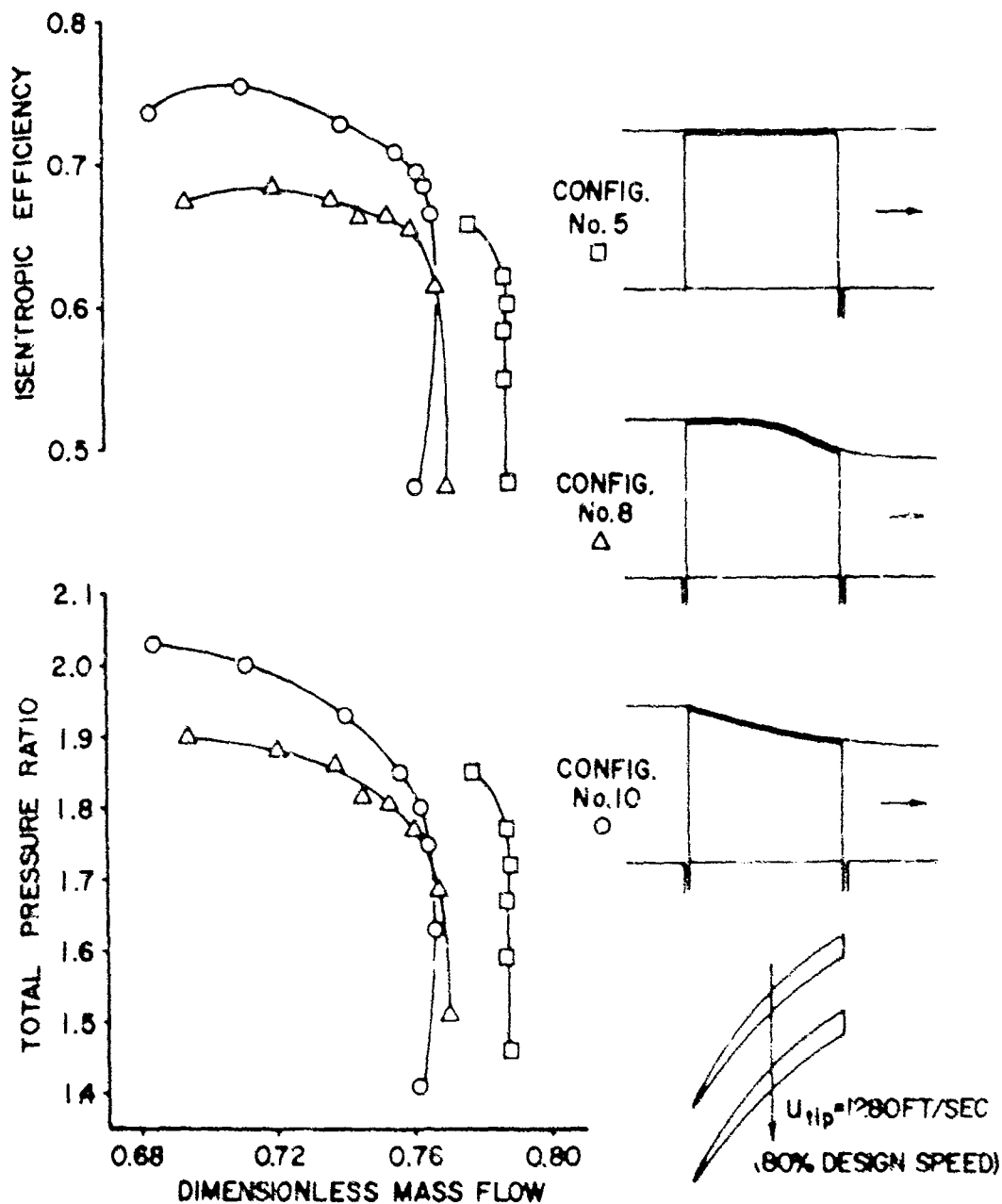


Figure 1. Supersonic-compressor-performance evolution: one-blade configuration; three annulus contours.

The examples presented represent some of the recent highlights of ARL's supersonic-compressor research conducted by Dr. Arthur J. Wennerstrom, and were selected to give an indication of the overall scope of the current research program. Most of the difficulties encountered in extracting better performance from supersonic compressors can be traced to the accumulation and separation of various fluid boundary layers. As a result, the current emphasis of the program is on understanding how these boundary

layers react, and to what extent they may be controlled. Boundary-layer control is an old topic which has received much attention with respect to components, such as wings and supersonic inlets. However, for various practical reasons, it has been largely ignored for the supersonic compressor. Our current opinion is that this line of research may ultimately lead to the sort of technical breakthrough necessary to realize the potential of the supersonic compressor.

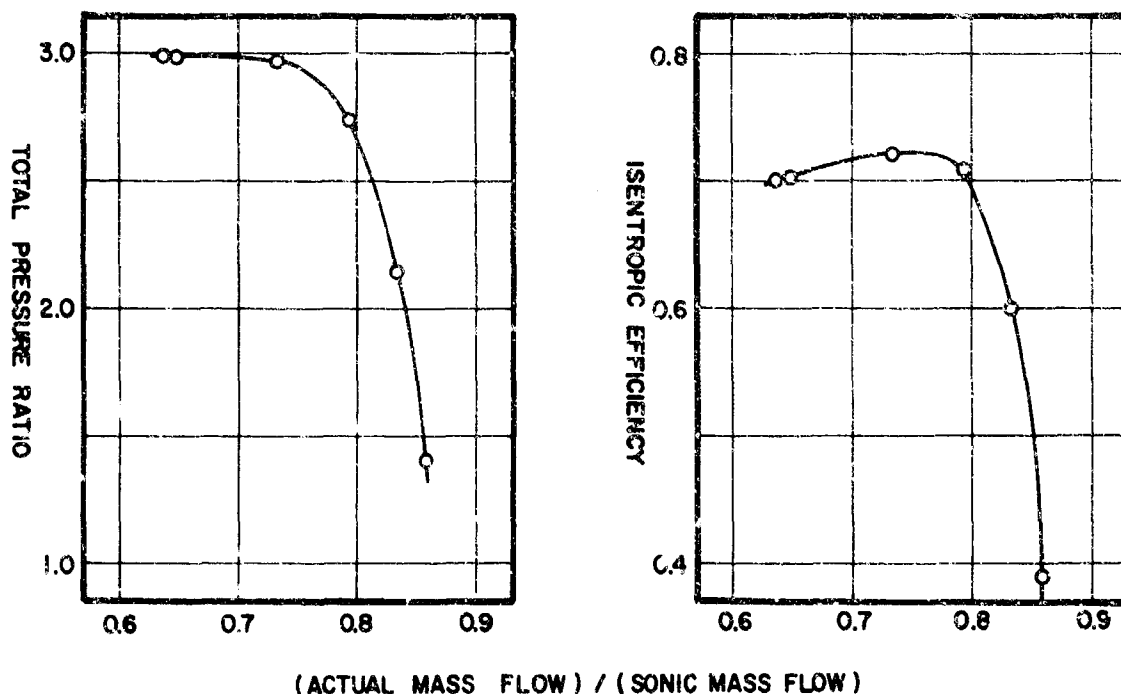


Figure 2. Mass-averaged rotor performance at design speed.

mechanics

DIRECT-SIMULATION MONTE-CARLO METHOD IN KINETIC THEORY

As the realm of operation of Air Force vehicles is extended to higher altitudes and greater speeds, the low densities and extreme velocities encountered make continuum theory inadequate for a description of vehicle motion and loads through the atmosphere. A new formulation, rarefied gasdynamics, is required, in which the particulate nature of the atmospheric gases is considered explicitly.

Although kinetic theory has had considerable success in deriving some of the macroscopic properties of gases from microscopic principles, it has serious deficiencies as a problem-solving method. First, kinetic theory is an abstraction, involving conceptual realizations of the state of a gas that are not easily related to physical-flow situations. Also, the fundamental equations of kinetic theory must be

extensively simplified in order to render them mathematically tractable.

In order to correct these deficiencies, Professor G. A. Bird of the University of Sydney has developed, with AFOSR support, a numerical simulation technique that produces a physically meaningful realization of flow problems, beginning with elementary molecular interactions. The basis of his "Direct-Simulation Monte-Carlo Method" is computer simulation of the trajectory of individual molecules. The problem of handling the enormous number of molecules in a flowing gas is resolved by applying statistical methods. While the molecular paths between collisions are calculated exactly, the computation of collisions is accomplished by random sampling.

This technique has been applied to a number of flow problems, such as plane shock-wave structure, hypersonic transition flow past various bodies, flow near the leading edge of a flat plate, structure of a spherical implosion wave, and the effect of a gravitational fluid on heat conduction. A recent development is the computer visualization of rarefied-gas flows. In this application the positions, paths and velocities of individual molecules can be displayed visually. Color coding differentiates among undisturbed molecules, molecules that have collided with

the body, and molecules that have been affected indirectly by the presence of the body. The resulting flow visualization has proved to be most valuable in studying the variation of the flow field past a body as a function of the rarefaction.

The "Direct-Simulation Monte-Carlo Method" promises to produce significant advances in several directions in rarefied-gas dynamics research: (1) flow visualization will be improved by using motion pictures of the computed molecular motions; (2) interaction potentials and molecular structures more complicated than the hard-sphere molecules used originally have been accommodated; (3) the good agreement obtained so far with experiment indicates that the simulation technique may be useful in inferring collision cross sections and surface interaction parameters, thus aiding the solution of those difficult problems.

The methods of Professor Bird have been applied recently by Thompson-Ramo-Woolridge, Inc., under Advanced Research Projects Agency support to obtain aerodynamic data for flows in the transition regime between free-molecule and continuum flows. They are also currently being applied to the hypersonic leading-edge problem. It is expected that there will be an increasing number of other practical applications in the immediate future.

mechanics

TURBULENT BOUNDARY-LAYER MEASUREMENTS AT HYPERSONIC MACH NUMBERS

Research on turbulent boundary layers at hypersonic Mach numbers has been carried out by Dr. Anthony W. Fiore at ARL's Hypersonic Research Laboratory. Measurements were made on the wall of both a contoured and a conical nozzle in the 4-inch hypersonic wind tunnel. The measured parameters were the total pressure and temperature across the boundary layer. Tests were conducted at a ratio of wall temperature to stagnation temperature of 0.35. The Mach number varied from 11 to approximately 12, and the Reynolds-number range, based on momentum thickness, was from 915 to 1600. The method of analysis used was the Baronti-Libby transformation, which converts the hypersonic data into the incompressible plane by mathematical iteration upon the incompressible skin-friction coefficient.

Figure 1 shows the velocity profile at the nozzle outlet plane for both nozzles. In general, the agreement between the experimental data and the theory is found to be very good. The data clearly indicates the region of the laminar sublayer, which appears to

be approximately 25% of the total turbulent boundary-layer thickness. In addition, it shows a typical overshoot found to exist at hypersonic Mach numbers when compared with the linear portion of the "law of the wall." Another point of interest is shown in Figure 2 where, for the same data, a plot of the total enthalpy ratio is presented versus the velocity ratio. It should be noted that the data does not follow the Crocco theory; however, two distinct regions appear to be present. In the outer edge of the turbulent boundary layer, the data follows the quadratic law, while the inner portion (the laminar sublayer) follows a linear law. This deviation from the Crocco theory is believed to be the result of the previous upstream history of the boundary layer. Finally, the ratio of the compressible skin-friction coefficient to the incompressible skin-friction coefficient is plotted versus the Mach number in Figure 3. This data is compared with both experimental data obtained by other investigators as well as with Spalding-Chi theory. Both the contoured- and

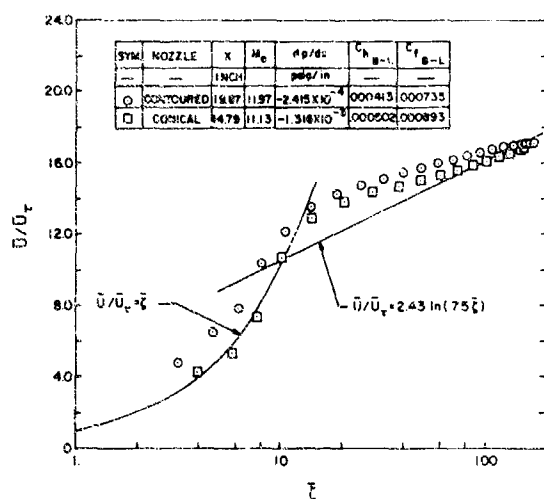


Figure 1. Velocity profiles at nozzle outlet for $R_{e0} = 1289$ and $T_w = 851^\circ R$.

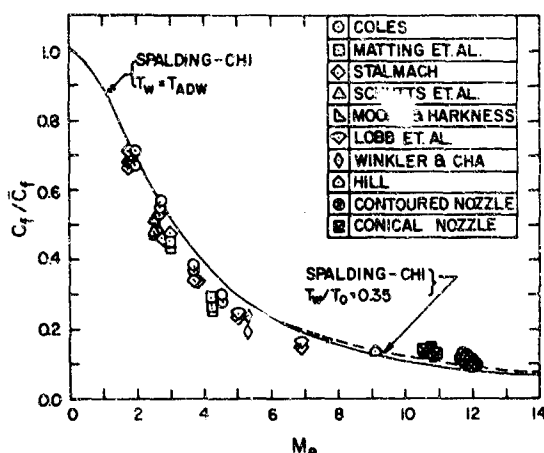


Figure 3. C_f/C_f versus Mach number for both nozzles compared with Spalding-Chi and other available data.

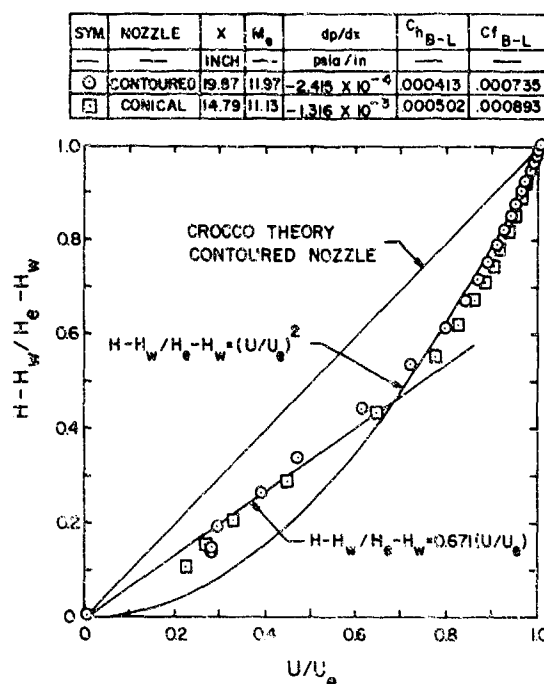


Figure 2. $H-H_w/H_0-H_w$ versus U/U_0 at nozzle outlet for $R_{e0} = 1289$ and $T_w = 851^\circ R$.

conical-nozzle data agree very well with the trend of the data as well as with the Spalding-Chi theory.

The general knowledge gained from this research has been very useful in understanding the characteristics of turbulent boundary layers encountered while flying at hypersonic speeds. Of particular value to the designer of future Air Force hypersonic vehicles will be the information gained concerning the skin-friction drag and heat-transfer rates expected at these flight conditions.

mechanics

INTERACTION OF A BLUNT-FIN SHOCK WAVE WITH A FLAT-PLATE BOUNDARY LAYER

In supersonic flow, the bow shock wave of a blunt fin protruding from a surface interacts strongly with the boundary layer on the surface. The pressure rise across the shock wave can cause the boundary layer to separate far upstream of the fin leading edge and result in extensive regions of separated flow, with substantially increased surface pressure and high heat rates in regions of flow reattachment. Furthermore, a peak pressure and local hot spot occur on the fin leading edge as a result of separation. The peak aerodynamic heating rate can be several times larger

than anticipated if separation effects are neglected.

From an applications standpoint, flow degradation and structural integrity problems can arise due to such strong interactions from fins, vertical control surfaces, and nozzles mounted on the compression side of high-supersonic and hypersonic vehicles. A vivid example of the severity of such interactions is the burnout of a pylon on the X-15 experimental aircraft. A quote from *X-15 Status Report No. 67-10* of AFSC's Air Force Flight Test Center, following the 3 October 1967 flight at $M = 6.72$ and 98,000 ft, is

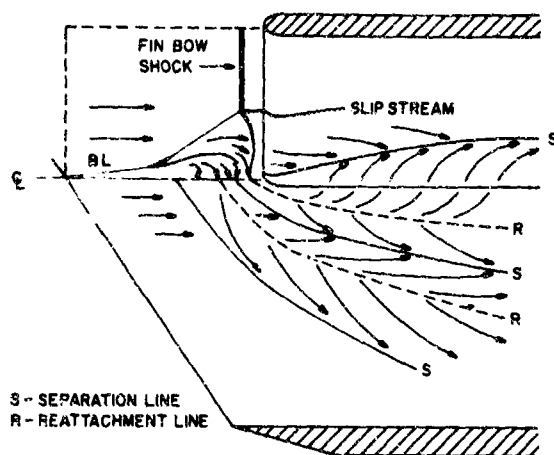


Figure 1.
Flow in the plane of symmetry and on fin and plate surfaces.

significant: "A total failure of the ablator and melting of the Inconel-X dummy ramjet pylon leading edge occurred because of the unexpected magnitude of shock-wave boundary-layer interaction heating."

In order to obtain a better understanding of the basic flow phenomena for this type of interaction, an experimental investigation was conducted by ARL's Hypersonic Research Laboratory, using a simple flat-plate model with slat fins tested at $M = 3$ and 5

at AFSC's Arnold Engineering Development Center. This work is reported by Lt Col F. L. Young, Dr. L. G. Kaufman II, and Dr. R. H. Korkegi, (1) with some results and observations noted below.

The interaction causes extensive regions of separated flow that are highly vortical in nature. Flow near the surface is scavenged outward from the plane of symmetry by means of one or more pairs of vortices, as illustrated in Figure 1. The vortices are bounded by alternate lines of separation and reattachment. Pressures along the fin leading edge in the interaction region rise to a local peak value considerably larger than the free-stream pitot pressure. Laminar separation ($--Re_{sep} < 10^6--$) on the plate is much more extensive than turbulent separation ($--Re_{sep} > 10^6--$), and depends on Reynolds number, whereas turbulent separation is insensitive to Reynolds number. The extent of laminar separation ahead of the fin increases with increasing Reynolds number, whereas turbulent separation occurs approximately 10 diameters upstream of the fin leading edge. Furthermore, the centerline pressure distributions on the plate surface upstream of the fin bow shock location are similar to those for two-dimensional separation occurring ahead of a step-like protuberance on a flat plate, for both laminar and turbulent separation.

mechanics

PLASMA ELECTRON DENSITIES FROM DOUBLE-SLIT INTERFERENCE PATTERNS

Thermodynamic and transport properties of plasmas are needed for various Air Force applications such as the development of nose cones, radiation sources, arc heaters for wind tunnels and materials testing, and for propulsion systems. A basic thermodynamic property is the electron density which plays an important role in the radiative, thermal, and electrical characteristics of a plasma.

Mr. P. W. Schreiber of ARL's Thermomechanics Research Laboratory, in conjunction with the thesis program of the Air Force Institute of Technology, is conducting research in interferometric plasma diagnostics designed to measure local electron densities as a function of plasma temperature.

For plasmas in local thermodynamic equilibrium, electron densities may be estimated by applying Saha's equation. However, this calculation is affected by the lowering of the ionization potential caused by the interaction between particles. Theoretical methods which have been used to estimate this effect

are questionable. Thus, it is necessary to compare these analytical results directly with measured electron densities in order to determine which theory gives the better representation of reality.

Experimentally determined electron densities are also subject to errors because questionable theoretical calculations are used in the reduction of the measured data. The common methods relate the electron density to the width of spectral lines or to the refractivity of the plasma. The first method usually requires the introduction of an impurity into the plasma; the second method is complicated by the additional effects of atoms and ions. In addition, past measurements have required expensive equipment (e.g., a Mach-Zender interferometer) and considerable training for its use.

In order to approach this problem from a simple experimental viewpoint, a double-slit differential interferometer was developed and used to measure electron-density distributions in a stable, free-burning

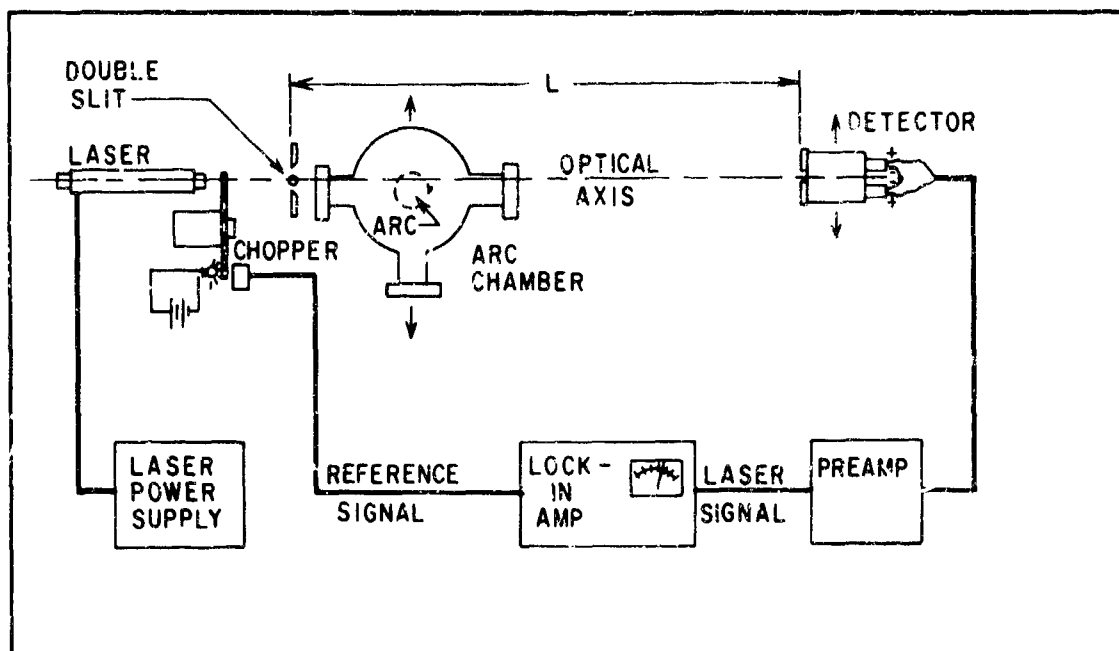


Figure 1. Diagram showing arc source and double-slit interferometer.

argon discharge at 1.1 atmospheres of pressure. As shown in Figures 1 and 2, a He-Ne laser illuminates the double slit with parallel, coherent radiation so that a double-slit interference pattern is formed at the

detector position. As the plasma is moved in the lateral direction, the lateral shift in the central peak of the interference pattern is recorded. The integration of these data represents a Mach-Zender fringe.

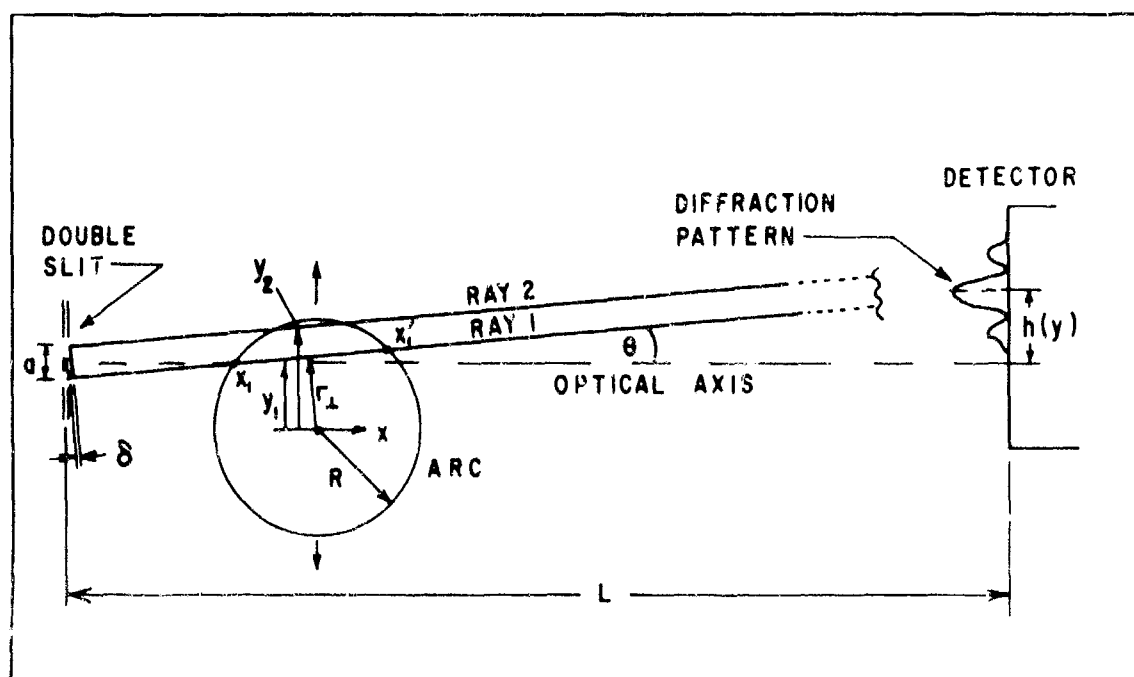


Figure 2. Geometry of the double-slit interferometer (top view).

The equation for the refractivity of a plasma was investigated, and a technique was developed which significantly reduces the error caused by atoms and ions. This is achieved by using a number of different wavelengths. These data are then expressed as an Abel-type integral equation which may be solved to yield the radial electron-density distribution. In addition, the double-slit interferometer allows measurements to be made in the infrared which enhances the contribution of electrons to the refractivity. Thus, good results may be obtained with a smaller number of wavelengths, and the accuracy is improved.

By using appropriate laser mirrors, data were obtained at 0.6328, 1.15, and 3.39 microns. These data were analyzed to yield electron density as a function of the plasma radius. In addition, the corresponding temperature distribution was measured in the free-burning argon discharge. Because of the data-reduction technique, the measurements have a minimum error at approximately 10,500°K. These results are compared in Figure 3 with calculated electron density as a function of temperature, thus confirming the thermodynamic calculations.

A careful analysis of the errors associated with this simple interferometric technique is being pursued. Hopefully, accurate measurements over a larger temperature range will lead to definite experimental information on the lowering of the ionization potential in plasmas of interest to the Air Force.

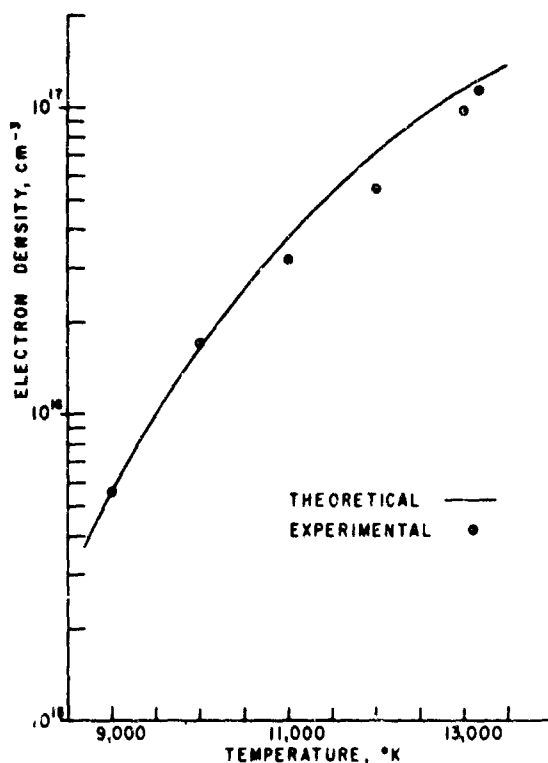


Figure 3. Comparison of experimental and calculated electron density as a function of temperature.

mechanics

STREAMWISE VORTEX FLOWS AND RELATED CRISS-CROSS ABLATION EFFECTS ON THE FOREBODY OF REENTRY VEHICLES

Several years ago, ARL's Thermomechanics Research Laboratory's Heat-Transfer Group initiated a search for information to explain observed heat transfers markedly higher than those predictable by the then-current heat-transfer theories. Investigators at Brown University, a contract participant in this program, explored the presence of vortex systems in the flow, and also the influence of favorable streamwise pressure gradients. At about the same time it was learned at the Laboratory, in its heat-transfer research on separated supersonic flows, that Professor J. J. Ginoux of the von Karman Institute for Fluid Dynamics near Brussels had found unexplained periodic streamwise striation disturbances in the reattached supersonic flow on rearward facing steps. ARL researchers felt that these disturbances could be related to the Taylor-Görtler vortex systems predicted many years before, and added an investigation of such systems to their program. Further experimental evidence from other sources disclosed the

presence of these periodic disturbances, and revealed analytical evidence that they could markedly influence heat transfer. It has now been reasonably well established from our work at Brown University and from the work of Professor Leif N. Persen of Trondheim, Norway, the Laboratory's special investigator on this subject, that these disturbances are vortex systems which must be expected in certain classes of curved flows.

At a recent meeting at AFSC's Space and Missiles Systems Organization (SAMSO), it was disclosed that reentry flight vehicles showed unanticipated and unexplained criss-cross striations on their ablative forebody surfaces. Dr. Max G. Scherberg, the representative from ARL's Thermomechanics Research Laboratory, felt that the above effects were almost certainly related to the streamwise vortex systems being investigated as part of the Laboratory's program, and added the criss-cross problem to the

program. Professor Persen, who had been working with the Thermomechanics Research Laboratory on the streamwise-vortex-systems' program, had reported earlier in correspondence that he had observed such a system in the water flow on the bottom surface of his kitchen sink when the tap was running. Dr. Scherberg felt that we had in such a water-flow setting an excellent experimental device for not only studying the vortex systems of the program, but also, with the use of a surface coating, the simulation of the ablative process occurring on the reentry flight vehicles. His theory was that periodic striation erosion from the vortex systems would initiate periodic bow-wave systems which would result in final criss-cross striation.

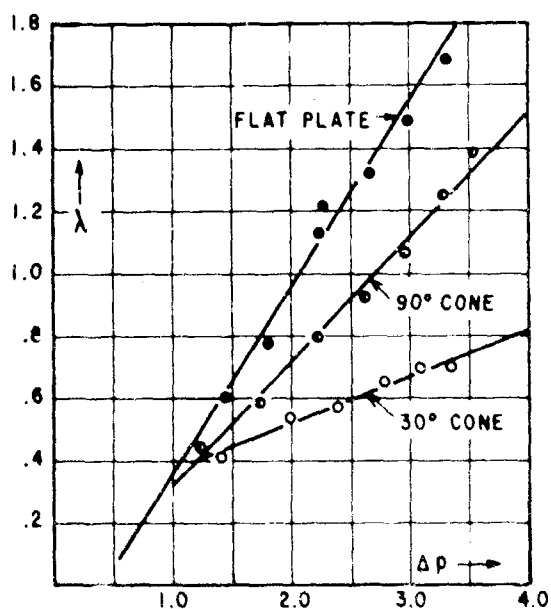


Figure 1. Results showing λ as function of Δp for the three models. Nozzle: 3/8".

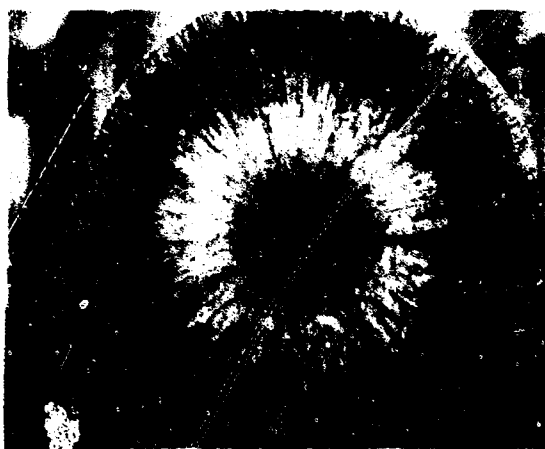


Figure 2. Striations on a plate (high jet speed).

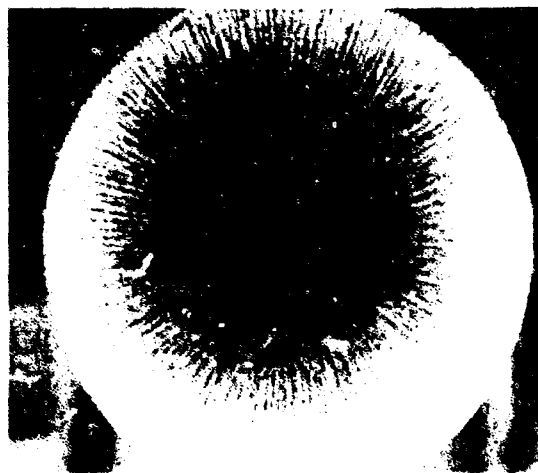


Figure 3. Striations on a plate (low jet speed).

Streamwise directed vortices have been investigated both theoretically and experimentally over the last 40 years. Those best known to the profession are the Taylor vortices appearing between rotating cylinders, and Gortler vortices appearing in the boundary layer along concave walls. Even though these "classic" cases have been known for a long time, it is only recently that the importance of such vortices in many practical applications has come to the fore. The appearance of Gortler-type vortices in the reattachment region behind backwards-facing steps was exhibited by Ginoux, and later also by the research group of the Douglas Aircraft Co. Large increases in heat transfer in the stagnation region have been studied by Kestin and Gersten, among others; this increase has been thought to be caused by streamwise-directed vortices.

Some theoretical work is currently being conducted in this area, but many questions still remain to be answered. Among these are: 1. What are the mechanisms of vortex formation, and under what conditions are they initiated and maintained? 2. How are the vortices, which are experimentally determined to be periodic, related to the prime flow characteristics? 3. Does the observed condition of increased pressure and velocity gradients, along the family of curves orthogonal to the streamlines when these vortex systems appear, indicate an instability in curved flow systems which will prohibit a stable two-dimensional flow system? 4. How do these vortex systems erode surface coatings and produce the periodically distributed striations observed in these coatings? 5. How do the vortices affect ablating surfaces to produce the criss-cross striations found on reentry vehicles, and in comparable tunnel tests?

Actually, some of these questions have already been answered in a qualitative way. Water-jet experiments, a follow-up to the Trondheim kitchen-sink

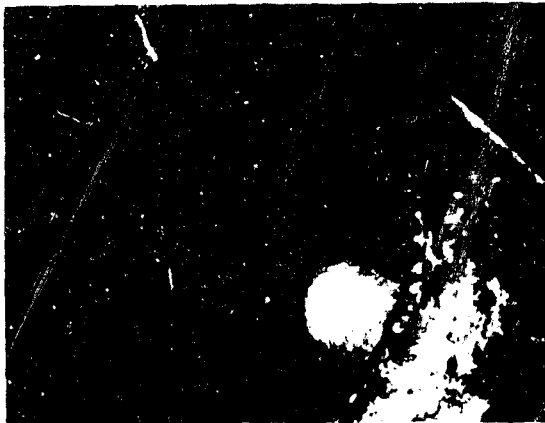


Figure 4. Criss-cross pattern in the water surface (flat plate).

experiments, show that the vortex distribution frequency is proportional to the speed of the jet (see Figure 1). Figures 2 and 3 show the striations in undried paint surfaces at two different jet speeds.

Some approximate primitive analysis has indicated certain pressure and velocity gradients having opposite directions can produce an unstable curved flow system. The water-jet experiments appear to indicate that local flow separation in a flow system containing the streamwise vortex system can produce the criss-cross striations referred to above (see Figure 4). Disturbance bow waves from eroded paint surfaces did not at first appear to be strong enough to produce criss-cross erosion in the paint coating.



Figure 5. Criss-cross pattern in the water surface (water table).

although a criss-cross wave system was visible to the naked eye. The criss-cross system was finally obtained in the paint coating at lower flow speeds and softer paint coatings so that the viscous erosion forces and the bow-wave pressure differences were comparable. Figure 5 shows a conventional flat-plate water table on which the criss-cross wave system originates at the sharp bend at the bottom of the waterfall.

energy conversion

PHOTOSYNTHETIC ENERGY CONVERSION

Photosynthesis is nature's way of converting low-grade energy into energy useful to man and his environment; it is a series of processes in which electromagnetic energy is converted into free chemical energy. Future space technology may be required to duplicate and use photosynthesis for sources of energy for extended space missions.

The photosynthetic apparatus is a lamellar structure which can be considered as an array of solar cells where chlorophylls (photosynthetic pigments) act as a modified p-n junction. The cells are charged by light-absorbing chlorophyll pigments. Water is the electron source and oxygen is a reaction product, accompanied by the reduction of the electron acceptor to energy-rich compounds. At present, the detailed mechanism of photosynthesis is obscure, and many questions need to be answered. Drs. E. Fujimori and K. P. Quinlan of the Energetics Branch of AFRL's Space Physics Laboratory are attempting

to answer some of these questions, such as: What are the photophysical states of the photosynthetic pigments? What is the molecular mechanism of a chlorophyll-sensitized reaction which effects the conversion of light energy into chemical energy? Is it possible to obtain useful energy from chlorophyll-driven reactions?

The interaction between light-excited chlorophyll and electron donors/acceptors has been demonstrated by means of electron spin resonance. Insight into the mechanism of these interactions has been obtained by studies of the effects of quenchers, pH and oxygen. These electron-transfer systems were also shown to possess the ability of generating photopotentials and photocurrents. It was found that these reactions are accompanied by the ejection of a proton. This has answered many long-standing questions, but has also raised many more: e.g., is the induced photopotential of the chlorophyll system

due to a proton-concentration gradient?

The environmental organization of chlorophyll in its natural state remains unknown. The high concentration of chlorophyll, and the presence of a nonfluorescent form of chlorophyll have suggested a study of chlorophyll aggregation. Aggregated chlorophyll molecules exhibit spectral and photochemical properties different from their monomer forms and can be responsible for the specific function of chlorophyll in solar-energy conversion. New forms of chlorophyll aggregates have been found in high dipolar solvents such as aqueous-formamide solutions. A study of these forms has shown that they did not possess any special properties for photosensitizing endothermic reactions; it has also shown that chlorophyll a and chlorophyll b forms can exist as a copolymer.

Studies on the effects of other small molecules (such as water, methanol and dioxane) on chlorophyll aggregates have demonstrated that aggregates do not

necessarily have to involve the cyclopentanone ring ketone of one molecule with the magnesium atom of another. These studies have also shown the variable types of interaction in aggregation. The methanol study has revealed that the phytol portion of the molecule may also play an important role in chlorophyll aggregation.

Investigations into the charge-transfer properties of solid chlorophyll have shown that dried solid chlorophyll forms charge-transfer complexes with the following electron acceptors: oxygen, p-benzoquinone, p-chloranil, p-bromanil, and iodine. It was found that the addition of water affects the chlorophyll-chlorophyll interactions, and produces a stabilized free radical which is attributed to the oxidized form of chlorophyll. The simulated lamellar composites of chlorophyll and p-chloranil were found to possess a light-induced voltaic effect. This phenomenon is being analyzed with the ultimate goal of developing functional solar-cell devices.

energy conversion

AMMONIUM PERCHLORATE

After the introduction of AP (ammonium perchlorate, NH_4ClO_4) into solid-rocket-propellant formulations some 15 years ago, this crystalline oxidizer rapidly became the principal ingredient of all large solid rockets for space and missile applications. Its practical advantages have clearly outweighed its disadvantages, and a considerable body of art has been built up on the processing and use of this material, mostly through trial and error.

At the same time, the fascinating complexities of the behavior of AP, both in the laboratory and in the rocket engine, have resulted in a great proliferation of research interest and research publications. A number of important scientists, in the U.S. and abroad, have continued work over the years on various aspects of the problem; but an increasing number of younger workers have also entered this arena. The fact that a number of these are associated with rocket manufacturers is an indication that an understanding of AP decomposition and deflagration, and of the ignition and combustion mechanisms of AP propellants, is not just an academic puzzler. Realistic, quantitative models are needed to improve the basis for rocket and igniter design, to assess the effect of burning-rate catalysts, to settle on the specifications for the purity and physical condition of AP for propellants, and to predict the effects of long-term storage and radiation on propellants.

Much of the "classical" work still being quoted and used—for example, the work of Friedman, (1) Schulz, (2) and Nachbar (3)—has come from

AFOSR-supported research. At present, the objective is to obtain more precise data on several questionable facets of ignition and decomposition, and to identify those experiments which have a good probability of deciding between competing, strongly held theories. Two of the efforts being supported are in the area of AP deflagration.

At the University of California (Berkeley), Dr. E. E. Petersen has developed a powerful technique for studying deflagration and deflagration limits. (4,5) By imposing a temperature gradient on a single crystal or pellet, and arranging the lowest temperature to a value below the deflagration limit, the crystal extinguishes during the process. This simple concept has permitted the accurate determination of the deflagration pressure limits as a function of ambient crystal temperatures by a quenching experiment. Therefore, the measurements are no longer dependent upon the magnitude of the ignition-stimulus strength as was true for previous measurements. This type of experiment is providing data for a unified theory of ignition and deflagration since, at the low-pressure deflagration limit, the ignition process coincides with the deflagration process.

During the past year, Professor H. C. Beachell of the University of Delaware has prepared the alkyl-substituted ammonium perchlorates and investigated their physical, chemical and combustion characteristics. (6) It was found that all of these mono-propellants had faster burning rates than ammonium perchlorate. Methylanmonium perchlorate was found

to have the highest burning rate—nearly three times that of ammonium perchlorate. Although the material was more sensitive to impact than ammonium perchlorate, and had lower melting and decomposition points, it proved to be a valuable new compound for studying combustion. These investigators had predicted that compounds like the alkyl-substituted APs, having a cation which is a better fuel than the ammonium ion, would have faster burning rates than pure AP. In addition, the burning rates are

expected to be faster than AP/hydrocarbon propellant mixtures because of a simplified mass transfer during the first steps of the overall combustion reaction.

This new information from both Petersen and Beachell is having an impact on the discussions now taking place in small, closed groups whose aim is to hammer out areas of agreement and disagreement, and come up with data needed for specific areas, such as the deflagration of AP.

energy conversion

ELECTROFLUID-DYNAMIC ENERGY CONVERSION

An increasing awareness of space and remote-area power requirements, such as high power-to-weight ratio, high reliability and long lifetime, has dictated heavy research emphasis on direct energy-conversion processes, that is, processes which do not employ moving mechanical parts. Analyses indicate that the conversion of fluid-dynamic energy into electrical energy by electrofluid-dynamics (EFD) or "fluid-dynamic Van de Graaff" generators (wherein an electrically insulating fluid transports electric charges of one polarity against an applied electrostatic field) may yield attractive performance characteristics complementary to other direct energy-conversion processes. ARL's Energetics Research Laboratory, under the guidance of Mr. M. O. Lawson, is engaged in research to establish the fundamental working characteristics of EFD power generators. Specifically, the research is directed toward a special recirculatory, two-loop cycle employing two working fluids, which was developed early in ARL's program. Present research rigs, however, only simulate the cycle using pressurized air in both flow loops (see Figure 1).

The hydraulic diameter has been established as the primary parameter coupling the fluid-dynamic and electrical fields. For the most attractive performance regime, the hydraulic diameter of the EFD channel should be very small (a fraction of an inch). As a result, research emphasis has shifted from power-limited cylindrical-channel geometries to small hydraulic diameter, two-dimensional channels (greatly elongated slots) capable of larger power outputs. The experimental test rig has the special form of a radial outflow geometry (see Figure 2) which has inherent manufacturing advantages. The primary flow discharges radially from a four-inch-diameter disk nozzle. Initial tests have concentrated on unipolar charge generation by corona discharge. Corona electrodes, both internal and external to the primary flow, are being studied. Due to the lack of electric-field divergency for the internal charging mode, however, best results have been obtained with

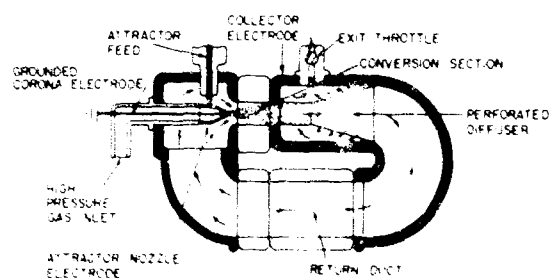


Figure 1. Recirculatory EFD generator, (closed-cycle simulation), schematic view.

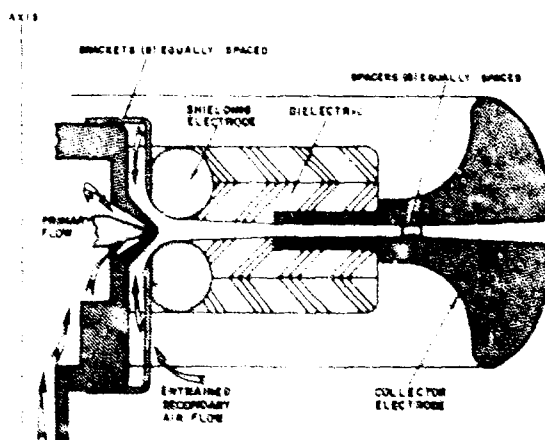


Figure 2. Radial-outflow experimental EFD generator.

the external corona electrode. The current value of one milliamperes at atmospheric pressure approaches analytical expectations.

A numerical computer program has been developed to calculate the electric-field structures corresponding to complex electrode shapes and charge distributions. Regions of peak electric-field intensities in EFD channels often lead to premature breakdown with decreased performance. Quantitative informa-

tion gained with the computer program has shown that the peak field intensities can be extremely large in the two-dimensional geometry. The potential gradient along the channel length can be effectively smoothed out, however, by providing electrode-shielding surfaces extending along the charge cloud. In the entrance region, the electrode surface should be immediately adjacent to the charges. The electrode surface then diverges such that the lateral distance between the outer boundary of the charges and the metal gradually increases. The lateral spacing depends on the charge density, the applied voltages, and desired potential gradient. Determination of the optimum electrode design, combining electrode-shielding requirements with aerodynamic characteristics, constitutes a major part of the present research effort.

The output voltage limitations of the conventional EFD channel configuration with dielectric walls have also been studied. Tests with cylindrical channels have shown that a 6-fold increase in length (1-6 inches) has increased the voltage level only from 400,000 to 600,000 volts. Due to charge deposition, the basic limit is a sparkover on the dielectric walls rather than an electrical breakdown of the gas. Since the charge-transport velocity on the wall is small compared to the main-flow velocity, even very small current leakages to the wall quickly lead to very large wall charge accumulation. Tests have shown that current leakage can be substantially reduced by controlling the humidity content of the secondary air

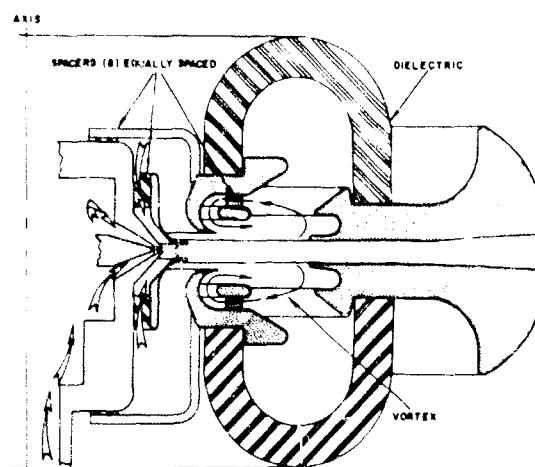


Figure 3. Radial-outflow experimental EFD generator.

flow to prevent evaporation of charged droplets. To insure no charge leakage to the walls, however, is extremely difficult. A more desirable solution is to remove the dielectric material from the immediate vicinity of the charges. This might be accomplished by a standing gas vortex (see Figure 3); charges which diffuse out of the main flow are then swept to the electrodes rather than accumulating on an insulator wall. The system is, of course, closed by an insulator which now is far from the charges and can have a large surface path length.

energy conversion

ADVANCED PROPELLANT CHEMISTRY

As a result of basic research sponsored by AFOSR's Propulsion Division, an orange-yellow solid-oxygen difluoride, (O_2F_2), is now being considered as a new rocket oxidizer. Most chemical substances which show promise as sources of energy are highly reactive materials. O_2F_2 is no exception.

The chemistry of oxygen difluoride is quite unique in that O_2F_2 reacts with most other substances at temperatures of -160°C or below. Even at these temperatures, a violent explosion occurs when O_2F_2 reacts with most organic or inorganic materials containing hydrogen. Many other reactions of O_2F_2 are so violent that there is a cleavage of most bonds, with resulting simple degradation products.

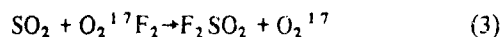
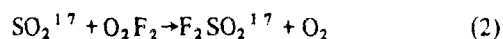
When a substance is so reactive, reaction studies are extremely difficult and dangerous. However, a team of researchers, headed by Dr. I. J. Solomon at the Illinois Institute of Technology's Research Institute (IITRI) has succeeded in sufficiently subduing

the O_2F_2 molecule so as to be able to study the chemical kinetics of its reactions with a number of other substances.

Dr. Solomon found that the reaction of O_2F_2 with sulfur dioxide (SO_2) could be controlled, and that this reaction was particularly useful in his study of O_2F_2 chemistry. The two compounds are frozen at -196°C and then warmed slowly until the reaction starts—at about -160°C . Reaction products are then collected and identified. The primary reaction was found to be $SO_2 + O_2F_2 \rightarrow F_2SO_2 + O_2$ (1)

Because O_2F_2 reacts so quickly, any attempt to examine the mechanism of its reaction by means of conventional kinetics studies is very difficult, if not impossible. Therefore, an oxygen-17 tracer technique was devised.

If reaction 1 is a simple fluorination, no oxygen should transfer from O_2F_2 to F_2SO_2 . This hypothesis was proved by carrying out the following reactions with O^{17} -labeled compounds:



The nuclear-magnetic-resonance spectrum of all reaction products was analyzed to determine the location of the oxygen¹⁷ tracer. It was found that the O₂ formed in Reaction 1 did not contain O¹⁷—also that the F₂SO₂ formed in Reaction 3 did not contain O¹⁷. Since scrambling was not observed, it was concluded that the F₂SO₂ was formed by a simple fluorination reaction. This pattern of reactivity correlates well with the atomic structure of O₂F₂ as determined by microwave spectroscopy. The O-O bond is relatively short and strong, whereas the O-F bonds are longer and weaker. (See Figure 1) Rupture of the O-F bonds initiates reactions and as the molecule its violent reactivity.

This basic-research program has progressed so well that AFSC's Air Force Rocket Propulsion

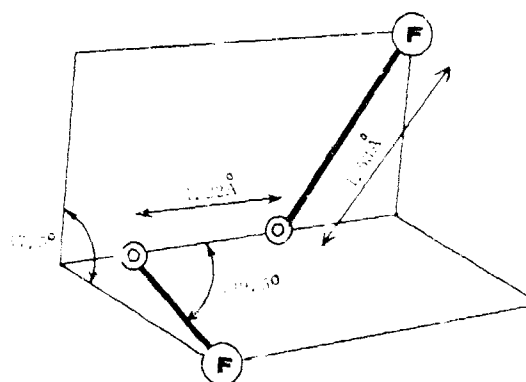


Figure 1. O₂F₂—one of the most reactive substances known.

Laboratory contracted recently with IITRI for the further development of oxyfluorides as potential rocket-propellant oxidizers.

energy conversion

PRODUCTION OF NEUTRONS BY VORTEX ANNIHILATION IN A PLASMA FOCUS

Plasmadynamics, the modern area of fluid-dynamics, is expected to have at least as many technological applications as aerodynamics has had in the past. The technological applications of plasmadynamics may be subdivided into many groups, depending upon the criterion of subdivision. However, for our purpose, the subdivision into iso-

energetic and nonisoenergetic that is, with release, will be followed. A large number of isoenergetic applications are available to date. These are MHD accelerators and generators, electronic devices and, lately, neutron-producing devices. The nonisoenergetic applications may include fission- and fusion-power plants.



Figure 1. $t = 250 \pm 20$ nsec. Current sheath is already crossing face of center conductor. Note vortex pair combining at 5 o'clock.

Neutron production by vortex annihilation in a plasma focus was investigated by Dr. Winston Bostick and his coworkers at the Stevens Institute of Technology with the support of AFOSR's Propulsion Division. They used a plasma coaxial accelerator having inner and outer conductor diameters of 3.4 cm. and 10 cm., respectively. The length of the inner conductor was 13 cm. The accelerator was driven by a 45-microfarad capacitor bank having a maximum voltage of 25 kilovolts. The working fluid was deuterium of 10^{-2} atm. pressure. At a voltage of 13 kilovolts, the energy stored by the capacitor was 3.5 kilojoules and, during the discharge, the resulting peak current reached a value of 0.5 megamp. The half-cycle time was 2 microseconds.

During the pulsed operation, when the current sheath collapses in the "pinch" at the end of the center conductor, the plasma vortices are observed to annihilate each other. Thus they produce a region of bright illumination which moves at a speed of 200 km/sec. from the end of the center conductor along

the axis.

During the operation, two main neutron pulses appear: a) the first neutron pulse occurs during the vortex annihilation along the axis while the bright region moves from the center conductor to the crown of the umbrellas (see Figures 5 and 6); b) the second main neutron pulse is associated in time with the vortex annihilation occurring in the crown of the umbrella. Then the vortices "burn" in pairs, and a magnetoshockwave moves radially outward from the crown of the umbrella (see Figure 3).

Bostick and his coworkers have advanced the idea that the observed vortex annihilation, as shown in Figures 1 to 6, is the laboratory analogue of the solar-flare phenomenon. In their experiments the neutron yield produced was about 5×10^6 neutrons per pulse.

Figures 1, 2 and 3 are five-nanosecond, axial-view, image-converter photographs of the filamentary vortices. Figures 4, 5, and 6 are profile views of the aforementioned vortices.

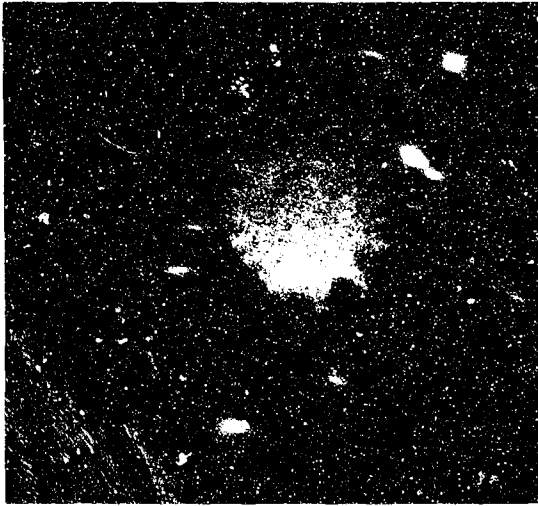


Figure 2. $t = 10 \pm 30$ nsec. "Plasma Focus" has occurred.

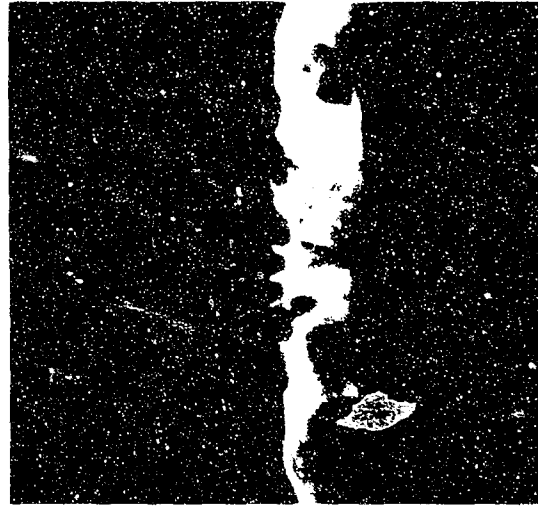


Figure 4. $t = -250 \pm 20$ nsec.

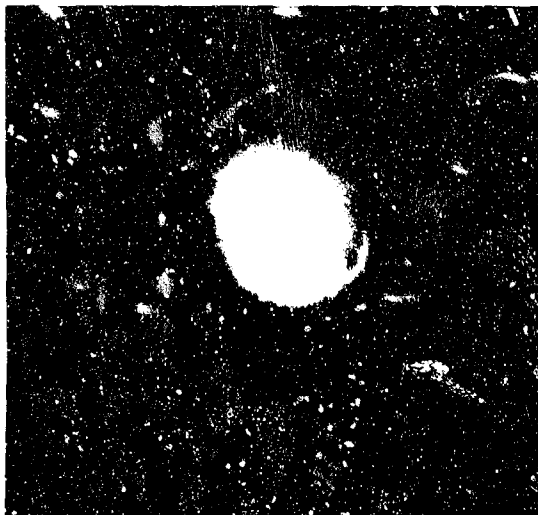


Figure 3. $t = 230 \pm 20$ nsec.

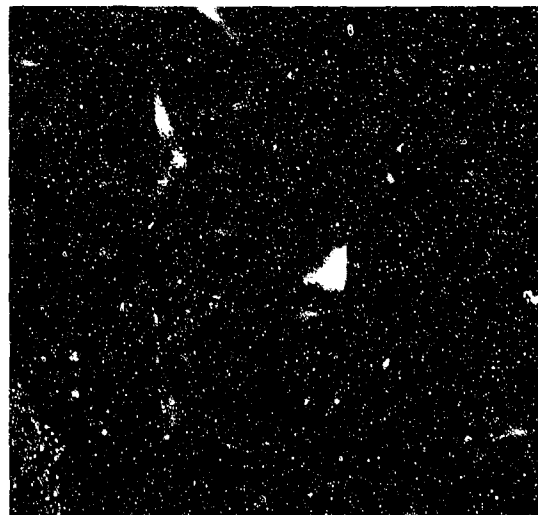


Figure 5. $t = 0 \pm 20$ nsec.

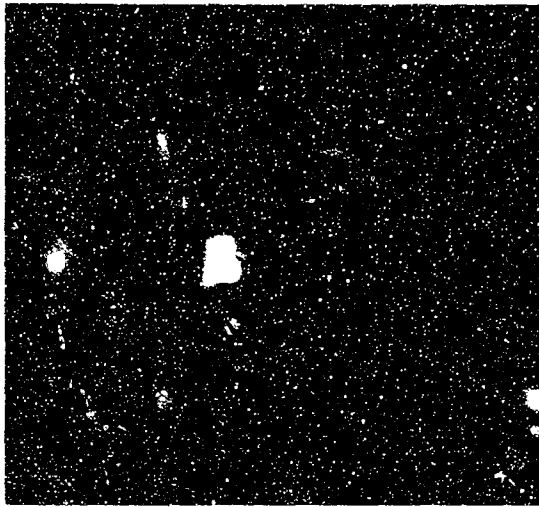


Figure 6. $t = 50 \pm 20$ msec.

terrestrial sciences

STABILITY OF AZIMUTH CONTROL

Numerous military and civilian systems and instruments require directional control lines for testing or calibration purposes. Such systems range from a large astronomical telescope, to an inertial guidance system, to a magnetic compass. With the advances in inertial navigation systems, the accuracy requirements for such reference lines have become stringent and exacting.

It is sometimes forgotten that any control line must be marked by some sort of monument that is fastened in some way to the earth's surface; hence, the accuracy of such a line depends upon the stability of its end points. In locales where long lines (e.g., 10-20 km) of sight are possible, slight instabilities of the end points are of little concern, except in regions of active tectonic faulting, such as in California. In flat topography, however, where only short lines are possible, the stability of the end points is of critical concern, for a mere 2.4-mm displacement on a 500-m line can cause an angular change of one arcsecond.

In a study of the influence of geological parameters on the stability of survey monuments, Mr. G. H. Cabaniss of AFCRL has discovered some interesting topographic effects and a partial solution to problems associated with short-line azimuth references. By applying a strain analysis technique to data from repeated surveys of control networks in the Midwest, he found that the long axes of the derived strain ellipses exhibited a strong NW-SE preferential orientation, as indicated in Figure 1. The long axes of the

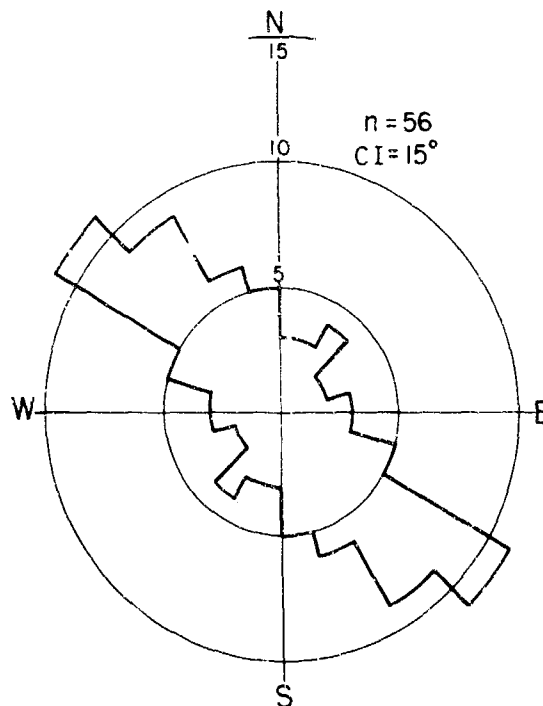


Figure 1. Polar histogram of the orientation of the strain ellipses derived from repeated geodetic measurements on 56 azimuth control networks.

ridges and valleys also showed the same trend in this region of gently rolling topography. This similarity

implies that the topography dominates monument movements; any random instability is of only secondary importance. A reasonable explanation for such a pattern is the differential downslope movement of the control markers, particularly those on the flanks of NW-SE-trending ridges.

Two implications arise from this interpretation. The first is that maximal angular stability of control can be achieved by orienting lines parallel to the

principal axes of the strain ellipse, that is, either parallel or perpendicular to the topographic slope. Secondly, the question must now be raised concerning the credibility of crustal-strain data derived from similar short-line networks in tectonic-fault zones. Except in the most active zones, the apparent strains associated with the topographic effects might be sufficiently large to completely mask tectonic strains and form a perfectly logical but spurious pattern.

terrestrial sciences

MEASUREMENT OF THE ABSOLUTE ACCELERATION OF GRAVITY

The best possible capability for this basic physical measurement is of primary importance to the Air Force. The absolute acceleration of gravity is required with high accuracy for the calibration of guidance and navigation instruments. In addition, several geodetic parameters contributing to the geodetic and gravitational error budget of ballistic systems also depend on the value of gravity acceleration.

The major obstacles to the achievement of high accuracy in experiments to measure absolute gravity by classical instrumentation and approaches are the systematic errors present in each particular experiment. In addition, classical experiments are not "transportable," so that intercomparison between laboratory experiments at different places has been possible only by relative gravity connections between the sites of the experiments.

To overcome these difficulties, B. Szabo and his coworkers at AFCRL have studied methods of obtaining high-precision measurements of gravity with transportable instruments by combining laser technology with recent advances in electronics. As a result, James Faller of Wesleyan University, with the support of AFCRL, has designed and developed the first laser-interferometer free-fall apparatus, according to the specifications.

The apparatus consists of a Michelson-type interferometer constructed with corner cubes instead of mirrors. The falling object is one cube of the optical interferometer. A stabilized helium-neon laser provides the brightness and coherence necessary to

produce high-quality interference fringes. The cube falls through a little more than 1 meter in a chamber evacuated to about 5×10^{-7} mm Hg (6.7×10^{-5} N/m²). The time counters are started shortly after release of the cube; one counter is stopped near the middle of the fall, and the other near the end of the fall. Gravity is calculated from the predetermined time intervals, the number of fringes counted, and the wavelength of the laser. The time base is a 5 MHz crystal oscillator; its frequency is compared with WWV2 frequency standard. The timing accuracy is about 1 nanosecond (10^{-9}). Single-drop accuracy is 1 part in 10^7 , and drop-to-drop scatter is 5 parts in 10^7 ; from 100 drops, internal accuracy (standard deviation) of 5 parts in 10^8 has been achieved.

During 1968, AFCRL used this portable apparatus to measure the absolute acceleration of gravity at Teddington (England) and at Sèvres (France), where highly accurate permanent-type experiments had been conducted. The results obtained by the laser-interferometer apparatus agreed with the values of the "classical" experiments within 0.02 milligal (2×10^{-5} m/s²). These excellent agreements indicate the absence of significant systematic errors in the experiments involved. The laser-interferometer apparatus was also used to obtain an absolute measurement in AFCRL's gravity-seismic observatory at Bedford, Mass. At this observatory, various gravity experiments utilizing different approaches will be intercompared in order to detect systematic errors and to establish an absolute gravity-base-station for the Air Force.

atmospheric sciences

RADAR INVESTIGATIONS OF CONVECTIVE PATTERNS IN THE CLEAR ATMOSPHERE

The detection and analysis of convective activity in the atmosphere is of considerable interest to the meteorologist; but knowledge about convective

regions is of particular concern to USAF operational personnel because of their effects on vehicles operating through these regions. For many years we have

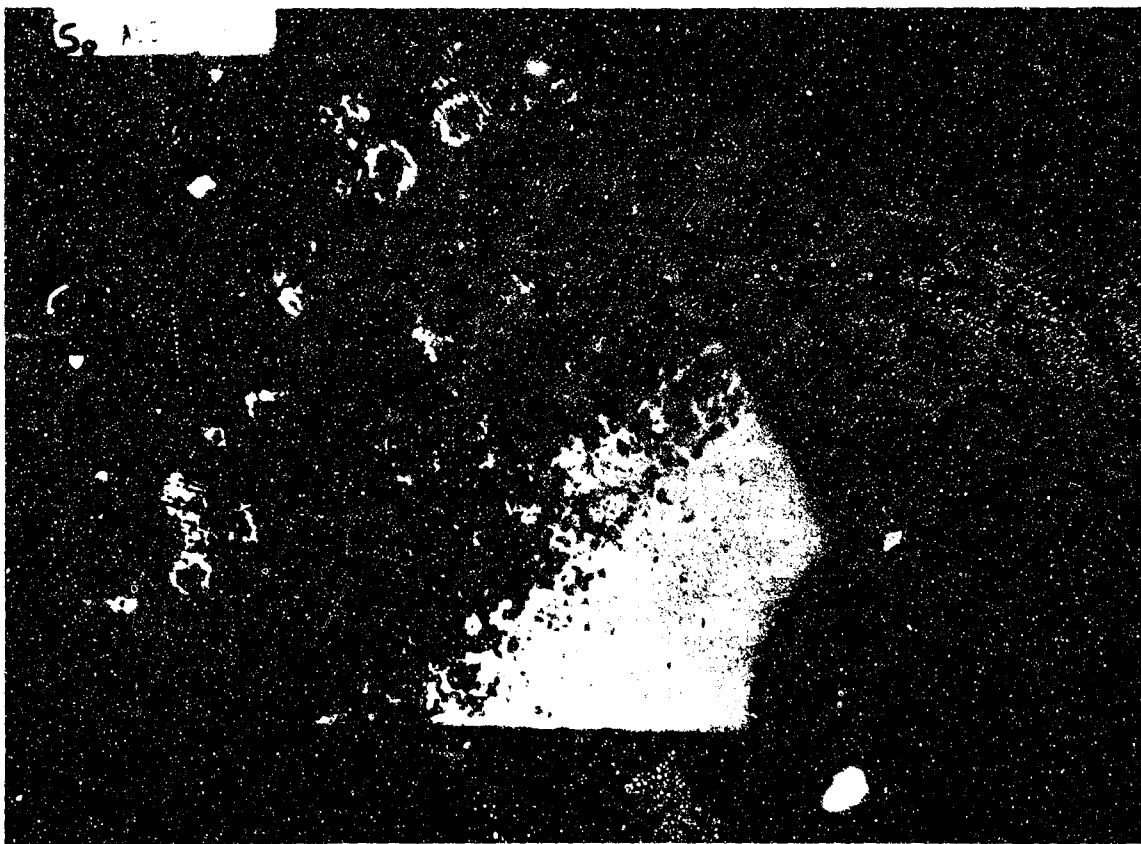


Figure 1. Sector PPI photo at 3-deg. elevation angle taken at Wallops Island, Virginia, at 1052 EST, 15 August 1967, with the 10.7-cm radar. The strobe line indicates the 300-deg. azimuth. Echoes of Type-I cells, in horizontal section at the appropriate altitude and range, display the characteristic doughnut shape.

had the ability, through visual or radar observations, to infer the locations of convective activity associated with strong cumulus development. However, in the absence of "visual" targets, such as clouds or precipitation, there was no means available for the remote observation of convective patterns, although such activity was known to exist. Recently, using ultrasensitive radars, meteorologists have also been able to detect regions of convection in a completely cloudless atmosphere, even though little was known about the character of these convective patterns.

Within the past year two AFCRL scientists, Dr. Kenneth R. Hardy and Mr. Hans Ottersten, have analyzed radar data collected at Wallops Island, Virginia, and at Sudbury, Massachusetts with a view toward establishing the form and evolution of convective motion in the clear atmosphere. They have found two types of convective patterns.

One pattern consists of small thermal-like cells (Type I) which are about 1-3 km in diameter and several hundred meters high. These cells may persist for 20 to 30 minutes. In a horizontal view, the radar echoes of these cells are doughnut-shaped (Figure 1);

their centers typically are echo-free. The structure of the cell and its time history are consistent with the view that the relative flow within the cell is upward in its center, and outward and possibly downward around its periphery (Figure 2). These clear-air cells are detected regularly with ultrasensitive radars at wavelengths greater than 10 cm. The echoes are caused by scattering from variations in refractive index, which are particularly marked at the cell boundary.

The other pattern is made up of clear-air Bénard-like convection cells (Type II) which are 5-10 km in diameter, and 1-2 km in height. The centers of these cells are also echo-free. The overall pattern may persist for up to 4 hours, and individual Bénard-like cells may have lifetimes of at least 30 minutes. The Bénard-like pattern is composed of several small cells organized around the circumference of the larger Type-II cells. These small cells are probably established through the same air flow that generates Type-I cells. Thus, it is expected that the Type-II cell will be characterized by cores of updrafts around its periphery, and by downward flow in its center. Echoes

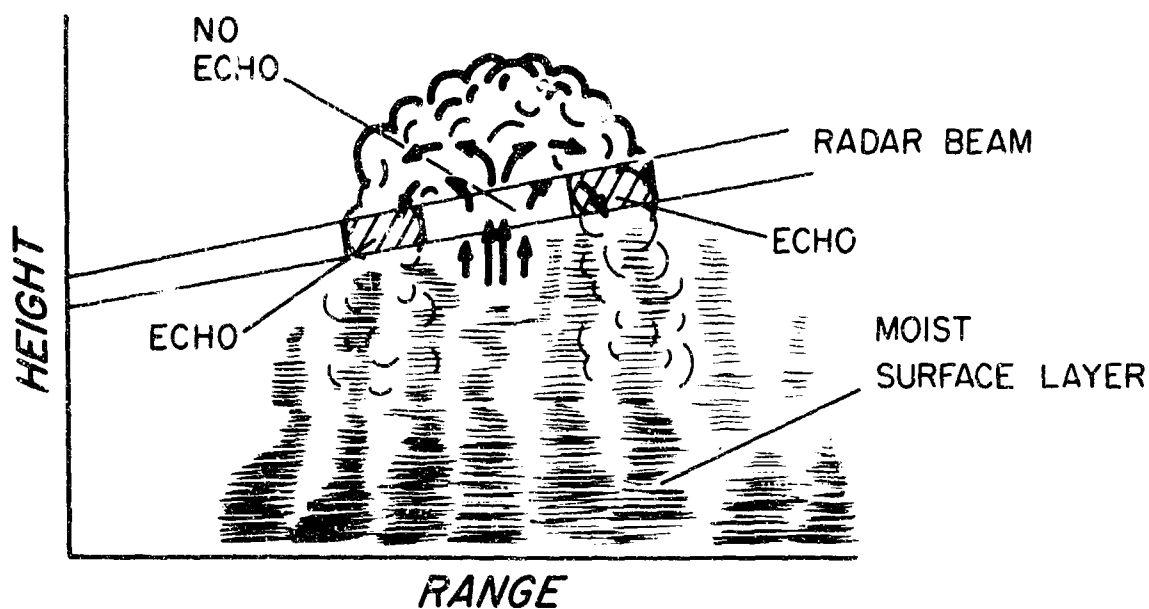


Figure 2. Sketch in vertical section of the Type-I cell structure. The radar outlines the boundary of the cell, where the refractive-index fluctuations are largest; when the radar is scanned in azimuth, a doughnut-shaped echo results. The air flow within the cell, indicated by the arrows, has been deduced from detailed studies of the cell's evolution resulting from the examination of three-dimensional radar patterns of individual cells. Type-I cells generally originate from a surface layer several hundred meters thick; this layer forms over the heated land area and is often outlined by weak radar returns from refractive-index fluctuations in the warm, moist air.

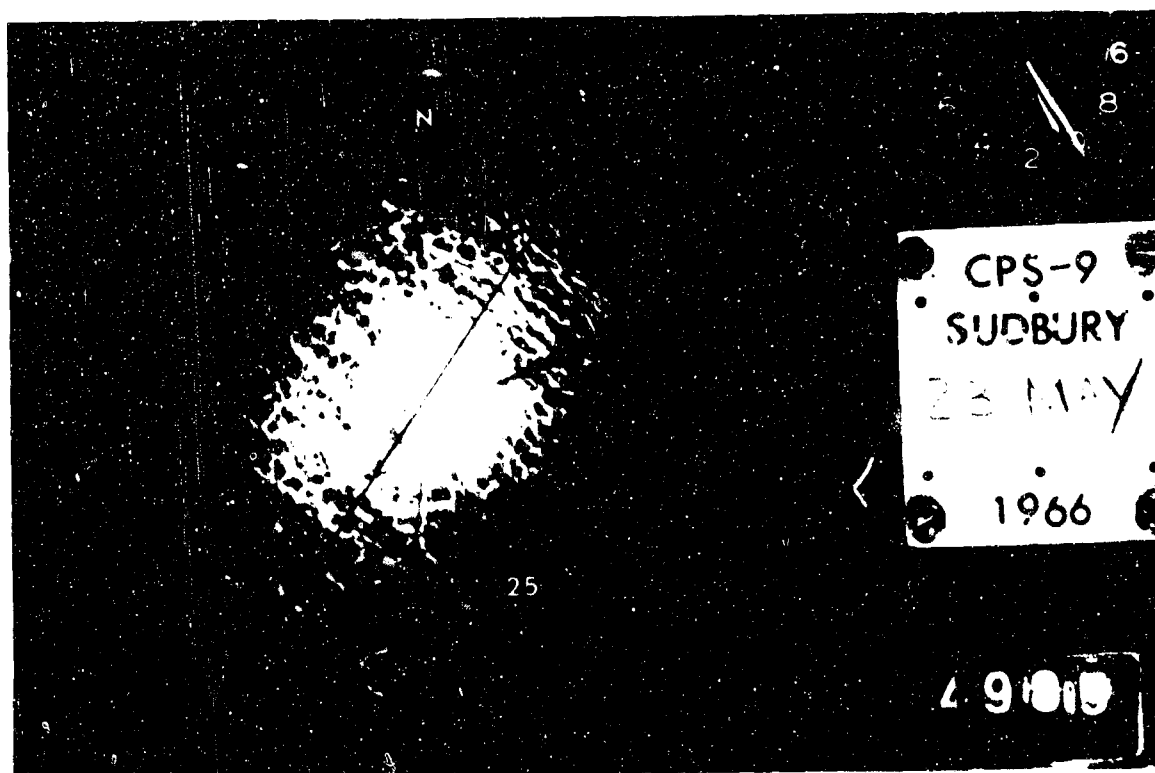


Figure 3. PPI photo at 0-deg. elevation angle taken at 1120 EST on 23 May 1966 while the sky was practically clear. The range marks are at 25-n.-mi. intervals. The radar is a 3.2-cm CPS-9 located at Sudbury, Massachusetts. A mesoscale cellular pattern, similar to the Bénard circulation pattern studied in the laboratory, can be seen. The echoes are due to scattering from insects.

from the Type-II Bénard-like cells were observed on three different clear days with a 3.2-cm radar of moderate sensitivity (Figure 3). These echoes were caused by the scattering from an unusually large number of insects, which served as excellent tracers of the air flow. Bénard-like clear-air patterns have also

been observed with sensitive 10-cm radars by virtue of the scattering from refractive-index fluctuations. The 10-cm radar observations confirm that the Type-II pattern is composed of Type-I convection cells organized around the periphery of the larger Bénard-like cells.

atmospheric sciences

OPTICAL PROPERTIES OF OZONE

Ozone, although a minor atmospheric constituent, produces significant effects in the upper atmosphere. It is the principal atmospheric absorber and emitter of electromagnetic radiation in this region and, to a large extent, governs the radiative heat balance, the circulation process, and the thermal structure of the stratosphere. Consequently, studies of the properties of ozone molecules are important to improve our understanding and knowledge, not only of the upper atmosphere, but also of the propagation of radiation through the atmosphere.

Ozone is a nonlinear molecule composed of 3 oxygen atoms; the equilibrium structure is indicated in Figure 1. The molecule has 3 fundamental modes of vibration (ν_1 , ν_2 , and ν_3) which are responsible for the more important ozone absorptions occurring in the atmosphere. Mr. S. A. Clough and his coworkers in AFCRL's Optical Physics Laboratory have obtained high resolution (the order of 0.07 cm^{-1}) of the 3 bands. Using theoretical formulations and high-speed digital computation, they have calculated frequencies for the approximately 5,000 transitions required to interpret the observed spectra. In most cases, these transition frequencies agree with the observed data to within 0.01 cm^{-1} .

A significant intensity anomaly, which was detected in the ν_1 band, is of particular interest. It became clear that conventional theory did not explain the appearance of this band, and that the interaction of the ν_1 vibration and the stronger ν_3 vibration must be taken more directly into account. This was achieved by including the interaction terms in a calculation which simultaneously gave the eigenvalues for both states; the results are indicated in Figure 2. The parameter r is a ratio that depends upon the degree of interaction of ν_3 with ν_1 . With $r=0$ (no interaction), the calculated spectrum bears little resemblance to the observed spectrum. With $r=10$, the relative intensities calculated are in satis-

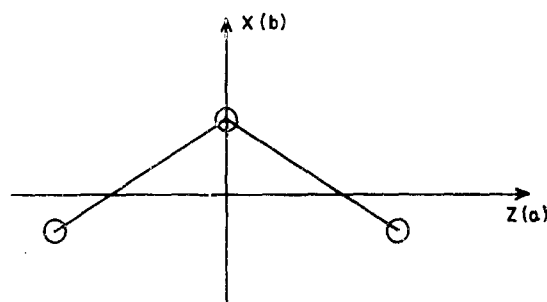


Figure 1. Equilibrium configuration for ozone.

factory agreement with the observations; deviations for the most part are attributable to the uncertainty in the estimation of the ozone amount in the experimental sample. These results confirm the importance of the interaction of the ν_3 vibrational mode with the ν_1 mode.

Another important parameter is the refractive index (optical dispersion) of ozone. The refractive index is a direct measure of the scattering (Rayleigh) cross section for ozone. Also, because of the increasing use of the longer wavelengths in the infrared region, values of infrared band intensities are needed at these longer wavelengths, and extrapolation of optical dispersion curves at the shorter wavelengths is required to obtain these band intensities.

The refractive index of ozone at 11 selected wavelengths in the region 3800 Å to 2.5 microns was measured by Dr. B. Schurin of AFCRL's Optical Physics Laboratory. Measurements of the ozone content of the samples were made with an accuracy of 1 part in 10^6 . The experimental results are shown in Figure 3, and compared with the calculated curve. This curve was obtained by estimating the small contributions to the index of refraction in the visible

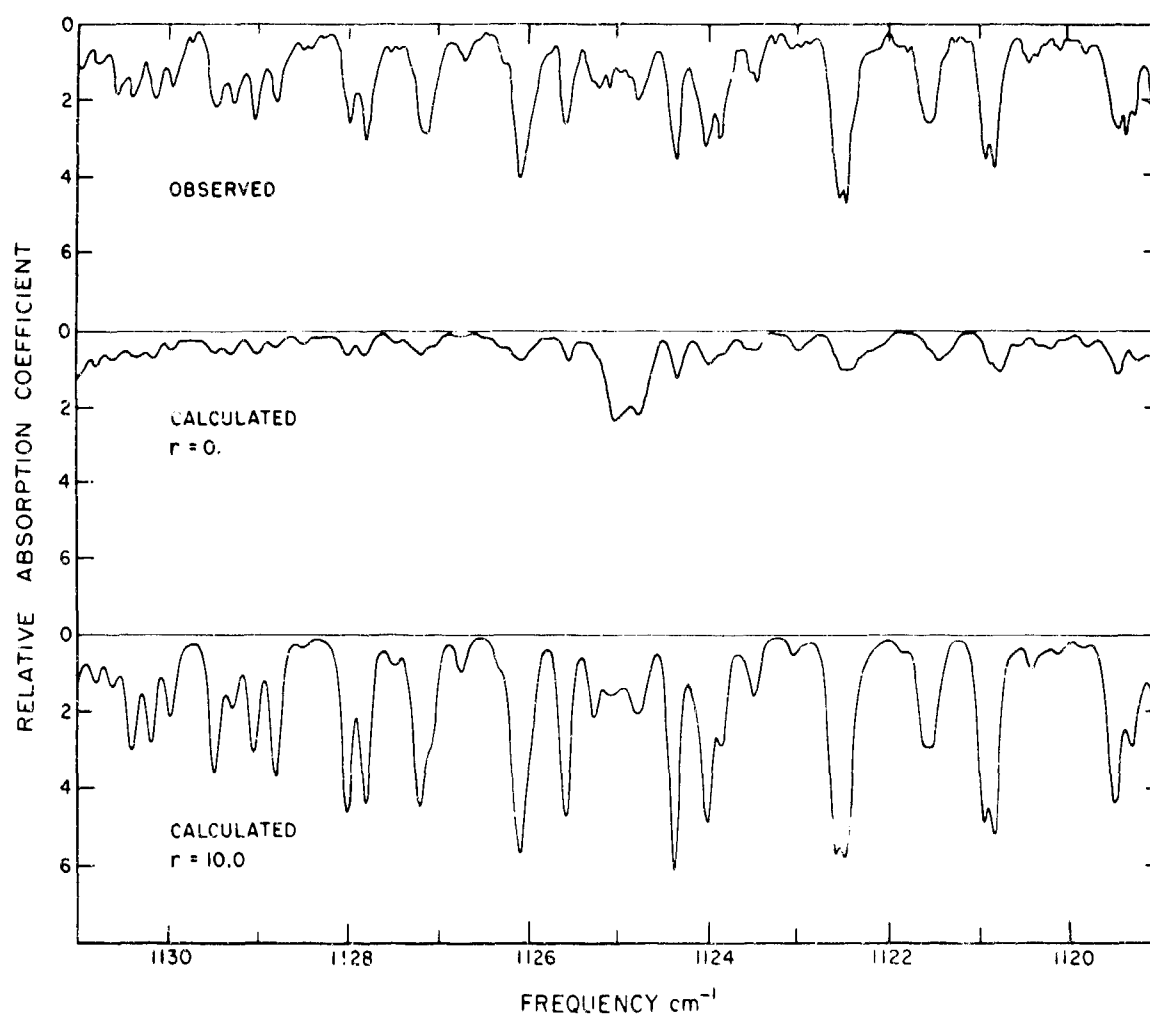


Figure 2. Effect of the interaction constant on the ozone spectrum.

region from the infrared bands at 4.0 and 9.6 microns; the contributions from the Hartley bands were then calculated. The residual curvature could then be fitted to an equation of the form

$$n-1 = A/(\nu_1^2 - \nu^2)$$

where ν_1 is a hypothetical absorption band center, ν is the wavenumber at which the measurements were made, and A is a coefficient related to the oscillator strengths of the ultraviolet and X-ray transitions. The calculated coefficients are:

$$A = 6.17 \times 10^6 \text{ cm}^{-2}$$

$$\nu_1 = 122,920 \text{ cm}^{-1}$$

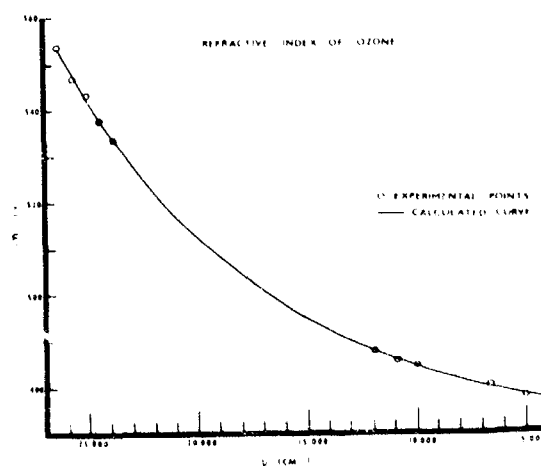


Figure 3. Refractive index of ozone.

atmospheric sciences

SATELLITE ATTITUDE SENSING

Since the advent of manned satellites, where it is desired to maneuver the spacecraft, there has been a need for a light, reliable and accurate attitude-sensing system. In order to fulfill this requirement, Mrs. Rita C. Sagalyn and Dr. Michael Smiddy at AFORL have designed a unique system which depends upon a positive ion-current flow from the surrounding plasma to determine vehicle attitude.

Such a system was successfully flown on the Gemini-X and -XII spacecrafts where the primary object of the tests was to compare the ion-sensor-attitude determination with the standard inertial-guidance reference platform. Figure 1 shows a comparison of this data for Gemini XII.

In a more ambitious project, the system was flown on the Air Force OV1-15 satellite launched in July 1968. This spacecraft was spin-stabilized and contained a number of attitude-sensitive experiments with the following stability requirements: to maintain the satellite within given limits of a desired attitude, and to know this attitude within 1 or 2 degrees.

The first objective was achieved by taking ion-attitude-sensor readings at approximately 45° either side of perigee, in real time, reducing this data to give spin-axis orientation in inertial space, and then initiating a magnetic torquing program to make the necessary corrections. The real-time sensor readings were outputs from the system which gave the angle between the sensor axis and the velocity vector directly. Because of the large angular range ($\pm 75^\circ$), this value was not accurate enough to use for postflight reduction. Consequently, the current flow to each component of the system was telemetered to earth and used for the final analysis.

The successful operation of the ion-attitude system on the OV1-15 spacecraft demonstrates its feasibility for other unmanned satellites where low power, weight, and long life are crucial.

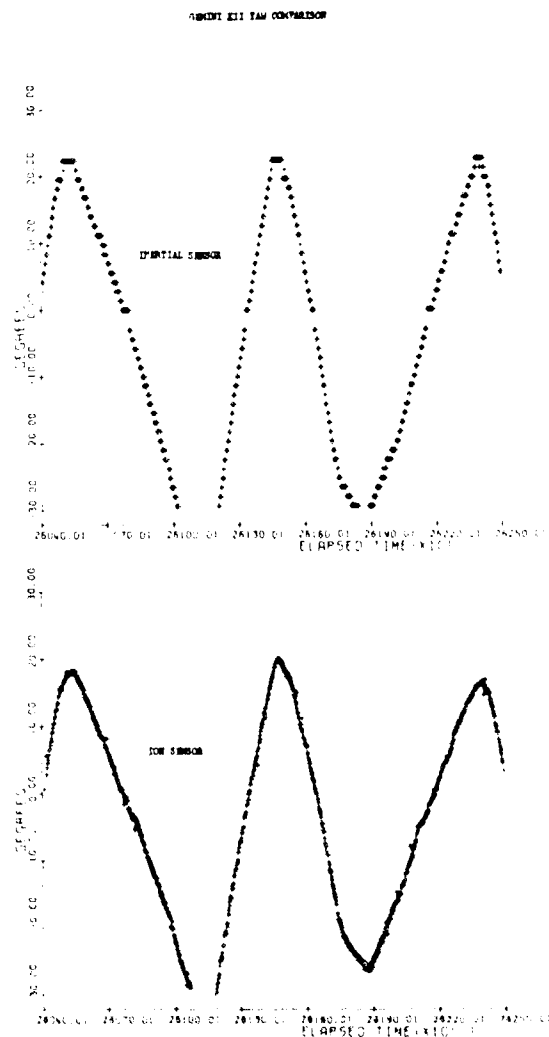


Figure 1.
Comparison of simultaneous yaw angular measurements by means of inertial and ion sensors, vs. time, from launch—Gemini XII.

astronomy and astrophysics

SIGNATURES OF SOLAR BURSTS

The system of classifying solar radio bursts by their spectra and their maximum flux densities, developed by the Radio Astronomy Branch of AFCRL's Ionospheric Physics Laboratory (see *OAR Progress*, 1968, page 101), has proved useful in several recent studies. Each radio burst during 3 monthly periods was classified and associated with an individual solar center of activity. It was then possible to determine if bursts from the same center of activity had a signature. The study revealed that a burst signature (spectral group) is associated with each center. However, as the magnetic configuration of the sunspot group changes, the spectral type of the bursts may vary, so that signatures may change over a period of time.

The spectral-group classification was also used in a study of Sudden Frequency Deviations (SFDs) and F-layer changes of height produced by solar-flare radiation in the few-hundred Angstrom region. High correlation of solar radio bursts in the 1000 to 5000 MHz region and SFDs was obtained. Low correlation was found with those radio bursts which had intensities decreasing with increasing frequency (the

Group-G spectra).

The spectral classification was used in a somewhat different manner by R. Straka and W. Barron of AFCRL. They integrated radio-burst signals at 606, 1415, 2695, 4995, and 8800 MHz, minute by minute. Their results, which are illustrated in Figure 1, indicate that radio events associated with polar-cap absorption (PCA) events show a characteristically large integrated energy in the decimeter range (below 1000 MHz), go through a minimum in energy around 3000 MHz, and then have a large integrated energy in the centimeter range (in the vicinity of 9000 MHz). Radio events not possessing this energy spectrum with corresponding sufficient amplitudes were not associated with PCA events. This is true even for a burst with single frequency energies above 10^{-17} J m⁻² Hz⁻¹ and, in some cases, even for a U-shaped intensity spectrum with fluxes greater than 10^{-14} W m⁻² Hz⁻¹ (1000 solar flux units).

Studies of this type contribute directly to our efforts to understand and to forecast environmental parameters which affect aerospace operations.

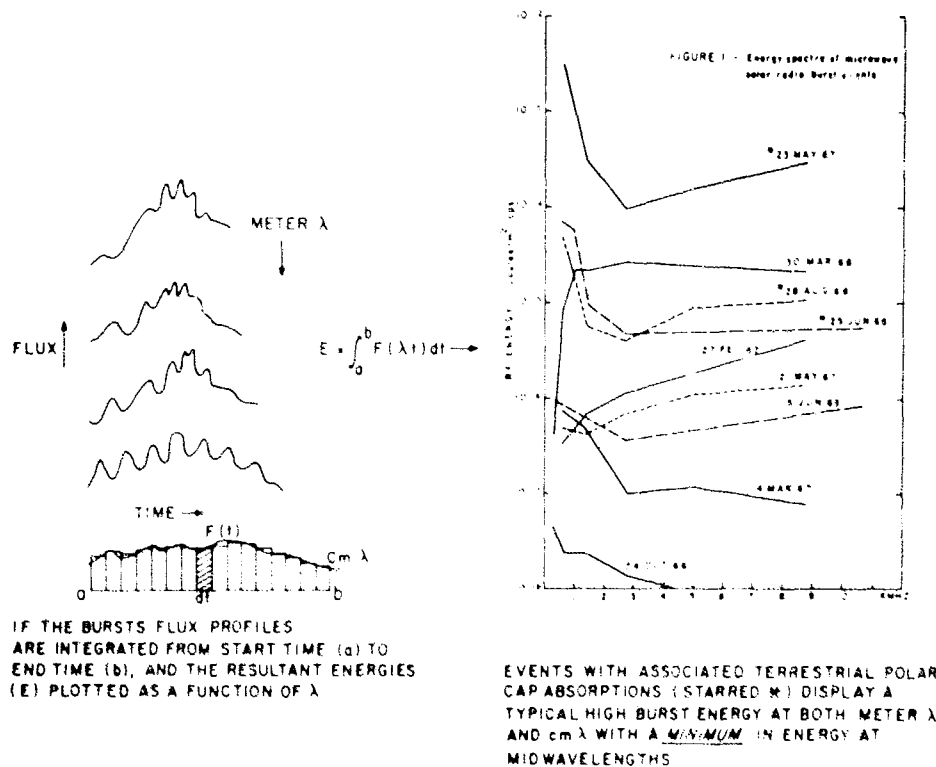


Figure 1. Solar radio-burst events.

astronomy and astrophysics

THEMAL ACTIVITY ON THE MOON

The moon is either a burnt-out cinder or, like the earth, it has a thermally active interior. There has been little evidence to prove or disprove one view or the other. This question has been hotly debated for years, since the presence or absence of internal heat bears directly on such problems as the origin of the lunar craters and the vast dark "seas" that cover much of the visible disk. Observations made recently by three lunar astronomers at AFCRL's Space Physics Laboratory suggest that the interior of the moon may still be thermally active despite the great age of parts of the lunar surface.

The evidence supporting this view grew out of the analysis of infrared images of the lunar surface obtained during the lunar eclipse of 13 April 1968 by Drs. Graham R. Hunt and John W. Salisbury, and Captain Robert K. Vincent. With the use of AFCRL's 24-inch telescope at Concord, Massachusetts, and a scanning device having a liquid-helium-cooled, copper-doped germanium detector, observations were made in the 8- to 14-micron range. By means of a thermal-enhancement technique developed by Dr.

Hunt, they obtained the highest-resolution images ever made during a lunar eclipse.

During the brief hour or so of a lunar eclipse, sensitive infrared instruments can record hundreds of hot spots on the moon. Previous AFCRL experiments have shown that most hot spots are simply areas of reradiated solar heat that has been stored in the lunar-surface materials.

Examination of the new eclipse infrared images uncovered a significant thermal anomaly in Mare Humorum, a small circular sea in the southwestern portion of the lunar disk (see Figure 1). Unlike most hot spots, this anomaly extended some distance along a line and coincided with a crustal fracture more than 100 miles long on the western "shore" of this mare. In the late lunar afternoon, when the areas on either side of this fracture had begun to cool, this area remained warm.

The thermal activity associated with this fracture was unlike that of any of the other hot spots. A number of possible explanations for this thermal anomaly were considered by the AFCRL scientists.

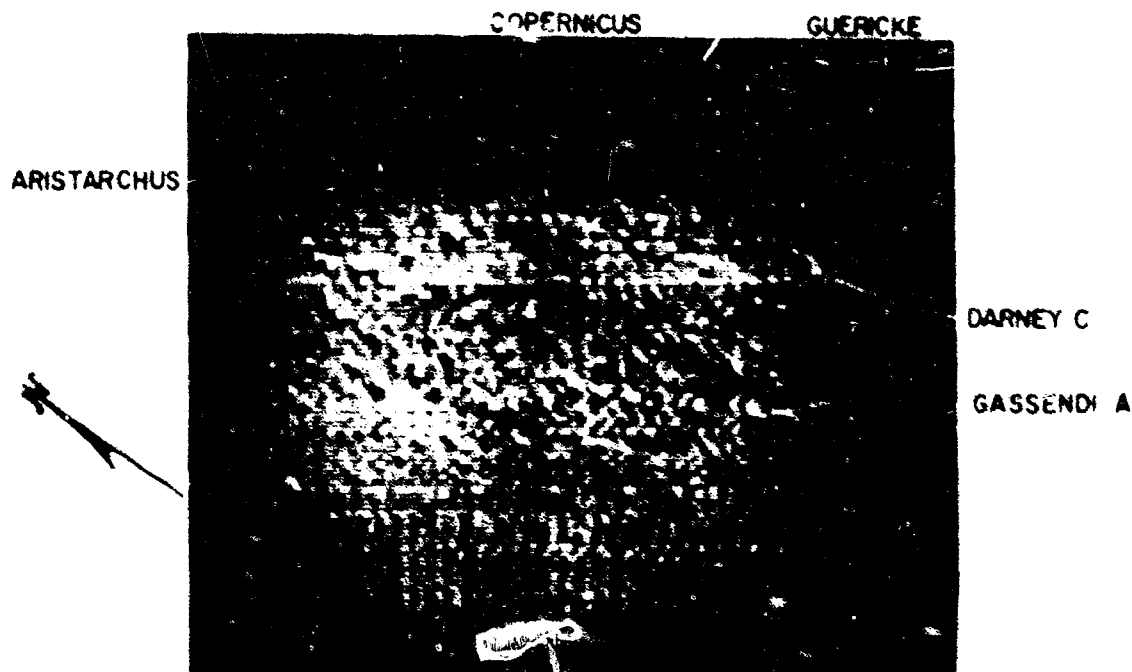


Figure 1. This photo shows an infrared scan of part of the lunar surface during eclipse. Hot spots are black dots in the picture.

One hypothesis was that the heat-absorption property of materials along the fault differed significantly from that of the materials on either side. Another possibility was longer exposure of the area to solar heating due to elevation or the angle of the escarpment to the sun. However, other evidence suggests that these are unlikely explanations. The most reasonable explanation for the thermal anomaly seems to be the existence of an internal heat source.

This conclusion is not without additional supporting evidence. The location of the anomaly along a line of crustal fracture suggests a natural access to an

internal heat source, as in the case of fracture regions on earth. Slow leakage of hot gases to the surface along the fault zone could provide an efficient heat-transport mechanism. In this regard, it is significant that there are at least 4 dark-haloed craters along the fault line, features which are generally considered to be due to gas explosions of internal origin. Also of interest is the fact that at least 12 reddish flashes or patches have been reported in the general area of the fault during the last 2 years. Taken together, the thermal and geological evidence suggests an internal origin for this thermal anomaly. It follows that the moon may not be a thermally dead body after all.

biological and medical sciences

RAPID DETECTION AND IDENTIFICATION OF PATHOGENS

No area in biological science has a more pressing need for study than the early detection and identification of micro-organisms. The AFOSR-supported program of John Gould, of the General Electric Company's Electronics Laboratory, to meet this need has resulted in the detection and identification of bacteria by gas-chromatographic (GC) analysis of metabolic products (1965), the detection and identification of viruses by GC analysis of interaction products with living cells (1966), and the application of the GC analysis concept to the preclinical detection of viral infection in horses (1967).

During the past year, publications on GC work have described two characteristic products observed in both serum and tissue cultures when both dogs and tissue cultures were inoculated with three different canine viruses. The objectives of current investigations are to determine the host specificity to particular viral infections, to gain insight into the well-being of the patient, and to develop a method for the rapid detection and identification of viruses. These studies are being continued with emphasis on human-problem viruses.

Work with bacteria during the past year has resulted in substantial improvement in their early detection by incorporating specific substrates in the culture medium. Work is in progress to enable early identification and more definitive signatures both in cultures and in the blood of animals infected with pathogens collected from human patients.

The use of gas chromatography for the detection and identification of micro-organisms has shown promise of being a rapid, sensitive, and relatively simple approach. Previous work has shown that

in-vitro detection and the identification of microbial metabolites is feasible by a GC analysis, and that the use of cometabolism measurably decreases the incubation period required for detection. Under the same program, it has also been demonstrated that a GC examination of reaction products resulting from viral infection shows promise as a means of virus detection and identification.

The following investigations are under way to further develop the concept that a GC analysis of host-virus interaction products will lead to improved methods for the detection and identification of viruses, and the early recognition of virus infection.

In-vitro studies designed to enhance the detection and identification of viruses, to provide knowledge of the mechanisms leading to improved qualitative and quantitative distinctions of viruses, are being conducted. Experiments are being conducted to define the serum fraction giving rise to an improved product spectrum—to note the effect of blocking the host m-RNA on the product spectrum—to observe the influence that different tissue cultures, in particular lymphocyte, kidney, tumor, and chick-embryo fibroblasts, have on the virus signatures—and to evaluate the use of labeled organic substrates.

In-vivo studies using germ-free mice for the purpose of achieving early recognition of virus infections are being pursued. Experiments will be conducted to increase the sensitivity by impairing the blood-clearance rate, to follow the course of infection by both GC and clinical techniques and to compare results from both germ-free and conventional mice with in-vitro tests.

biological and medical sciences

LYMPHATIC ABSORPTION OF DRUGS

Under AFOSR sponsorship, Dr. Ruth Levine of the Department of Pharmacology and Experimental Therapeutics, Boston University Medical Center, and Dr. Thomas J. DeMarco (now at Case Western Reserve University), have been conducting intensive research on the body's lymphatic system and its role.

The lymphatic system is an incompletely understood system when compared with the other circulatory, or blood, system. The exact channels and networks of the lymphatic system are not clearly defined, and its functional roles are poorly understood. While the primary role of the lymphatics in the intestinal absorption of dietary fats and certain other essential nutrients, such as Vitamin A, has been thoroughly investigated and elucidated, little attention has been directed toward studies of the degree of participation of the lymphatics in the intestinal absorption of drugs or chemicals. Therefore, a systematic investigation was begun to provide basic information about the lymphatics in both the intestinal absorption and the distribution of drugs. To the best of our knowledge, this is the first such investigation. The initial studies have shown that the intestinal lymphatics did indeed participate directly, though to a minor degree, in the absorption of the tuberculostatic agent, para-aminosalicylic acid. Lymphatically absorbed material gains access to the systemic blood circulation without first passing through the liver, where it could be subjected to metabolic degradation.

The antibiotic, tetracycline, although incompletely absorbed from the intestine as compared with para-aminosalicylic acid, is also partially absorbed by intestinal lymphatics. Significantly, both the total amount absorbed and the amount of tetracycline in intestinal lymph can be almost doubled in the presence of a fat (tripalmitin). Distribution studies

show that, after both oral and intravenous administration, the concentration of tetracycline in lymph is higher than in blood, in contrast to para-aminosalicylic acid where the concentrations in the two fluids were equal after either route of administration. This observation may have importance in the treatment of diseases associated with the lymphatic system. The therapeutic evaluation of other antibiotics might profit from the inclusion of studies on distribution as between lymph and blood.

Sufficient data has now been obtained to permit the assertion that the lymphatics serve as an accessory route for the distribution of any drug transferred across the intestinal epithelium. For nonprotein and nonsteroid drugs, this pathway assumes importance under conditions of decreased blood or increased lymph flow.

Studies with sulfonamides indicate that the amount of drug bound to plasma proteins has little influence on its distribution to lymph. After intravenous administration, both poorly and strongly bound sulfonamides were found in lymph in similar concentrations. Since the composition of lymph collected from large vessels, such as the thoracic or mesenteric, is assumed to represent that of extracellular fluid, it appears that either plasma-binding does not prevent drug distribution from blood, or our knowledge of lymph formation is incomplete. Presently accepted concepts of drug distribution must be questioned and reevaluated to be consistent with the new data.

The studies with sulfonamides were significant with respect to another aspect. The metabolism of sulfanilamide was found to be dependent on dose, being proportionately slower with higher doses. This fact may have therapeutic implications for this, and perhaps other, sulfonamides.

biological and medical sciences

CHEMICAL CONCEPTS IN LEARNING

With AFOSR support, Dr. Amedeo S. Marrazzi, formerly of the University of Minnesota, and now with the Institute of Psychiatry, University of Missouri, St. Louis, has conducted studies on the mechanism and drug modification of memory and learning. This study of information handling and learning, through their disruption by drugs, has brought the investigator close to the problem of drug

abuse, particularly as concerned with lysergic acid diethylamide (LSD), and 4-methyl-2,5-dimethoxy-alpha-methylphenethylamine (STP). It was found that disruption results because these substances, like the more-or-less closely related biogenic amines, impede communication within the brain, especially the recall of stored experience which is the basis of learning. Such effects in the main trunk (brain stem) connect-

ing the brain with the rest of the nervous system have been recorded. The generality of this finding throughout the brain has led to the concept that many drugs acting on the brain do so by modifying the brain's chemical communicating system. Microelectrodes positioned within brain cells are providing for an analysis of this possible action. The results of this analysis are expected to supply data on the key initial steps in learning which are thought to take place at the cell membrane.

It has been found that abnormal products of the chemical communicating system, like dimethoxyphenylethylamine (DMPEA) (which is found in the urine of some schizophrenics and Parkinsonian patients) do, like dopamine, distort the system in ways that might account for the diseases in which they are found. Dr. Marrazzi's related studies of STP link it to the action of LSD; while the interaction with chlorpromazine (CPZ)—protective in proper doses but aggravating in larger ones—reveals the nature of the tranquilizer action as a direct competitor of the hallucinogens. The design of a computer program and an electronic scanner of filmed records has accelerated the work and made possible the recording of pertinent electrical signals from the exposed brain (scalp) of humans. The direct assessment of

information deficits in adult mental disturbance, through the use of instrumental visual perception tests, will contribute to the realization of diagnostic possibilities.

In response to certain expressions of interest, the perception test room is being converted into a portable hand stereoscopic version which will be useable almost anywhere, and will allow ready screening for the potential breakdown point without inconvenience to, or the production of any symptoms in, the subject.

The further development of intracellular recording techniques by Dr. Marrazzi is bringing closer the utilization of experiments designed to detect the occurrence and nature of possible persisting post-synaptic cell-membrane changes essential to learning. Transynaptic influence on cell membranes is also being studied by attempting to monitor evoked potentials in the nervous system of the developing chick, where they may indicate synaptic development and have a bearing on the nature of transynaptically induced membrane changes such as might also occur in learning. If such changes can be monitored prior to the development of neurohumoral systems, a new dimension will be added to the quest for the mechanism underlying information storage and the production of memory traces.

behavioral and social sciences

USES OF HYPNOSIS

The phenomena of hypnosis have for so long been associated with either entertainment, or with magic and mysticism, that they have not received the amount of scientific attention they deserve for their significance and potential usefulness.

With the support of AFOSR, Dr. Ernest R. Hilgard at Stanford University has demonstrated that hypnotic phenomena can be subjected to orderly experimental, quantitative examination. This research has sought to identify the purposes that hypnosis can be made to serve, as well as its limitations. The two main directions of the research have encompassed studies of the recoverable forgetting that takes place after hypnosis (commonly called "posthypnotic amnesia"), and the reduction of experimentally produced pain (referred to as "hypnotic analgesia").

Four kinds of posthypnotic amnesia were studied: (1) spontaneous posthypnotic amnesia, occurring without any suggestion that there would be a memory loss after hypnosis; (2) suggested posthypnotic amnesia, in which the subject was told during hypnosis that he would have a memory loss

upon awakening until memory would be restored by a signal; (3) source amnesia, in which facts learned within hypnosis would be retained, but the fact that they were learned within hypnosis would be forgotten; and (4) amnesia produced by the drug, thiopental sodium (trade name: Pentothal Sodium).

The results were as follows:

(1) Spontaneous amnesia was found to be very rare, if indeed it could be attributed to hypnosis at all.

(2) Suggested posthypnotic amnesia is readily and convincingly demonstrable, but its amount varies from subject to subject. The amount of amnesia shown is a good indicator of the "hypnotizability" of the subject.

(3) Source amnesia may occur spontaneously, but subjects respond to the suggestion that the facts learned will be retained, and the fact that they were learned in hypnosis will be forgotten. Subjects often explain this by such a statement as "I must have heard it on TV."

(4) The amnesia produced by thiopental is of a

different order than that produced by posthypnotic suggestion. Materials learned while under the influence of the drug were, after sleeping and awakening, usually completely forgotten. Readministering of the drug did not bring back a remembrance of these items. In some cases the forgotten material could be restored to memory through hypnosis.

The use of hypnosis for the alleviation of pain appears to be its most promising application. Hypnosis was used as an anesthetic in major surgery before chloroform and ether even came into use. It is used successfully today by a number of dentists, obstetricians, and anesthesiologists. However, surprisingly little is known about pain reduction under hypnosis, from a scientific standpoint.

Dr. Hilgard used two methods for producing pain in the laboratory: (1) immersing a hand and forearm

in circulating cold water; and (2) applying a tourniquet to an upper arm followed by the exercise of the hand and forearm below the tourniquet.

Subjects who were hypnotized without suggested analgesia experienced very little reduction in pain. The relaxation associated with hypnosis was not sufficient to reduce the kinds of pain being studied. Under suggested analgesia, the pain was significantly reduced, with greater reduction for those who proved more readily hypnotizable.

Dr. Hilgard's research has provided substantial answers for those enthusiasts who continually push for the widespread use of hypnosis in Air Force training and operations. The results of his research caution against the uncritical use of hypnosis in Air Force applications other than in the induction of analgesia.

behavioral and social sciences

CROSS-CULTURAL INTERACTION IN A LABORATORY SETTING

Drs. E. R. Quarantelli and R. Roth of the Disaster Research Center at Ohio State University, under AFOSR support, have been conducting laboratory studies of communication performance of units under stress. Since late 1967 these investigators have focused on communication of a cross-cultural nature. Their work is based on the assumption that communication interaction between persons from different cultural backgrounds engaged in problem solving or training activities will involve stress. They have already come to the conclusion that cross-cultural interaction and communication can be meaningfully studied in a laboratory simulation setting.

Until recently, most research in this area had been done in one of two ways. First, there had been a series of studies which had attempted to determine the attitudes of foreigners towards the United States. The techniques most often employed had been questionnaires administered to, or interviews with, exchange students or government representatives from abroad. A second series of studies, using observational techniques primarily, had sought to analyze the types of problems an alien faces in a foreign environment. Such concepts as role conflict, culture shock, and cultural fatigue have been advanced. With the exception of several Air Force in-house efforts associated with training programs, there have been few attempts to create conditions in a laboratory setting in which the problems of cross-cultural interaction could be systematically studied.

The major objective of the Ohio State studies during 1968 was to determine whether the problems of cross-cultural interaction would manifest themselves, and lend themselves to study, in a laboratory setting in which graduate students from many nationality groups were used as subjects. The results were encouraging. The international subjects seemed to adjust as well to the laboratory setting and the demands of the research operation as the American subjects. A videotape play-back recorder was especially useful in making these preliminary observations.

The major finding of these preliminary studies was that, in cross-cultural interaction, members of both groups in the interaction will modify their normal behavioral patterns. Thus it is not enough, as early studies have done, to look only at the behavior of foreigners in the U.S. or at the behavior of Americans overseas in order to understand what takes place. The "native" group member in the interaction also changes his behavior in such situations. This observation suggests a convergence hypothesis, i.e., that members of all groups change their behavior in such a way as to come closer to the patterns of the other groups.

This behavior could be seen in both the length and type of contribution made by each individual to the group discussions on a controversial issue in which an effort was made to reach a decision. For example, American graduate students made significantly *longer* contributions than students from India

in groups composed only of each respective nationality; but Americans decreased the length of their statements, and Indians increased theirs, in the cross-cultural situation. Similarly, Americans increased the number of their supportive comments in the cross-cultural situation, and did this in a rather dramatic fashion. From two to three times as many supportive statements were offered by Americans in sessions involving international participants than were presented in the all-American group. In the same manner, the Indians decreased the number of their negative comments in a cross-cultural setting, regard-

less of the nationality group with which they were being compared.

Results from these sessions are being formulated into hypotheses for further testing. On-going experimental laboratory sessions will seek to determine how representatives of some 16 different nationality groups behave under the stress of an instructional situation. These experiments should provide information of value for Air Force training programs in which communication and interaction with foreigners are required.

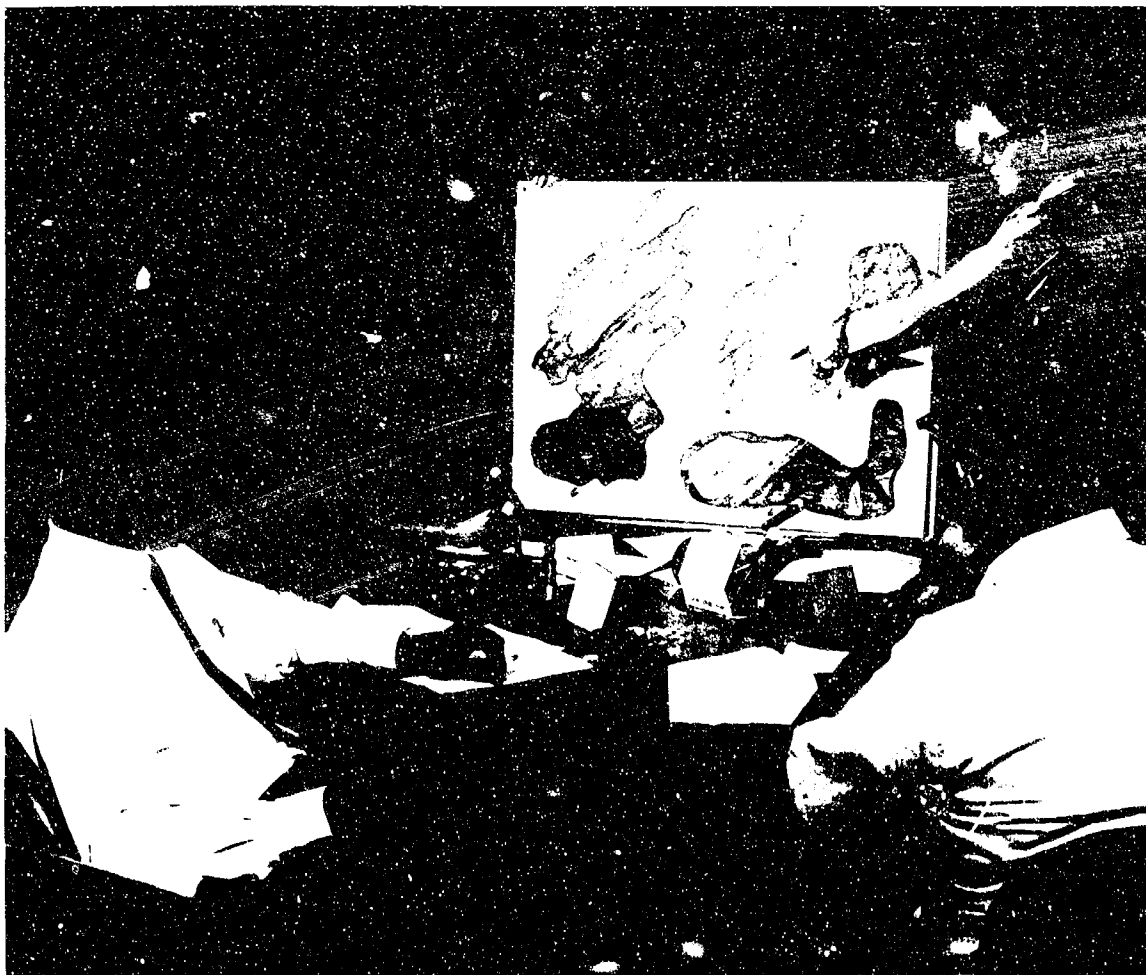


Figure 1. Student representatives from four different cultures interact while seeking a solution to a simulated international problem.

SELF-CONTAINED AUTOMATIC TRANSMITTER (SCAT)

The Air Force and other armed services are depending more and more on low and very-low frequencies for urgent communications under disturbed ionospheric conditions. Because of the long wavelengths involved, extensive antenna structures are required to obtain adequate radiation efficiencies. The antennas are commonly one or more very high towers with top loading, or cables suspended across canyons. A long wire trailing behind an aircraft in flight can also be used as a transmitting antenna. However, air drag tends to cause the wire to become more horizontal than vertical, thus degrading the coupling efficiency for propagating transverse magnetic (TM) modes.

AFCL scientists, led by Dr. E. A. Lewis, have demonstrated a new approach to sending urgent LF messages from aircraft. The concept is for the plane to carry an expendable, battery-powered device (SCAT) which can be dropped after the message to be transmitted has been read into it. As illustrated in Figure 1, the capsule contains a parachute, an upper reel of antenna wire, a solid-state transmitter, a battery pack, and a lower reel of antenna wire. When dropped, the parachute is deployed in stages, decelerating the device gently, and providing a long slow descent to the ground. (From an altitude of 45,000 feet, descent time to sea level is nearly an hour.)

Immediately after the parachute is fully deployed, the reels of antenna wire are released and "pay out" simultaneously. Special aerodynamic braking devices control the rate of wire release, obviating any sudden snubbing at the ends. When the reels are unwound, the transmitter is at the center of a half-wave dipole, hanging vertically from the parachute (for a frequency of 60 kHz, the dipole is 8,000 feet long). Being center-fed, the antenna impedance is

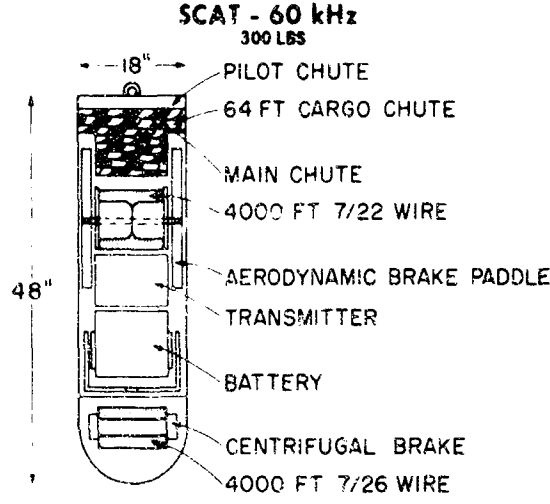


Figure 1. Self-Contained Automatic Transmitter (SCAT).

essentially resistive and low enough (90-100 ohms) to be conveniently driven by the solid-state transmitter.

Electrical tests conducted at the Army's Aberdeen Proving Ground (using a helicopter-supported unit) show that, with 7 strands of No. 18 copper-clad cable, a standard material—the radiation efficiency is about 80%. Using high-capacity, lightweight silver-zinc batteries, transmission times on the order of 30-45 minutes with a radiated power of 3 kw should be obtainable without exceeding an overall weight of 300 lbs. for the entire package.

Although a complete working model has not yet been assembled, the various individual elements of SCAT have been successfully tested to validate the concept.

MEASURING TOTAL ELECTRON CONTENT IN THE IONOSPHERE WITH THE NEW AFCL POLARIMETER

An aircraft navigation system that uses VHF pulses to determine aircraft position would have many advantages, for example, smaller antenna size and lower transmitter power. The disadvantage of using VHF is that propagation at these frequencies is seriously disturbed by ionospheric variations. Uncorrected daytime variations of total electron content of the ionosphere can introduce a delay in pulse-reception time equivalent to a range error of up to 10

miles. This error can be reduced to less than 1 mile if the total electron content along the path is known. A study of the diurnal and seasonal variations, solar effects, and latitudinal trends is necessary in order to catalog the changes and allow for corrections which would minimize ranging errors.

In the first stage of this study, conventional equipment for measuring polarization changes was used to determine simultaneously the total electron

content on the paths to 2 synchronous satellites that transmitted at 136 MHz. Because the conventional equipment was slow and the data obtained was tedious to reduce, Mr. John A. Klobuchar and Mr. Chester Malik of AFCRL's Ionospheric Physics Laboratory developed a new polarimeter which continuously yields polarization angle.

The results have been exciting. In 1968, AFCRL recorded several large solar bursts which abruptly

increased the total electron content. Figure 1 shows the continuous plots obtained for 2 large flares; the radiation increases the ionization in the F-1 layer, and the total electron content remains high. Disappearances of electrons were also recorded. During a severe magnetic disturbance on 1 November 1968, 60 percent of the total number of electrons in the ionosphere disappeared in 15 minutes, as shown in Figure 2. Other studies compared the effect of

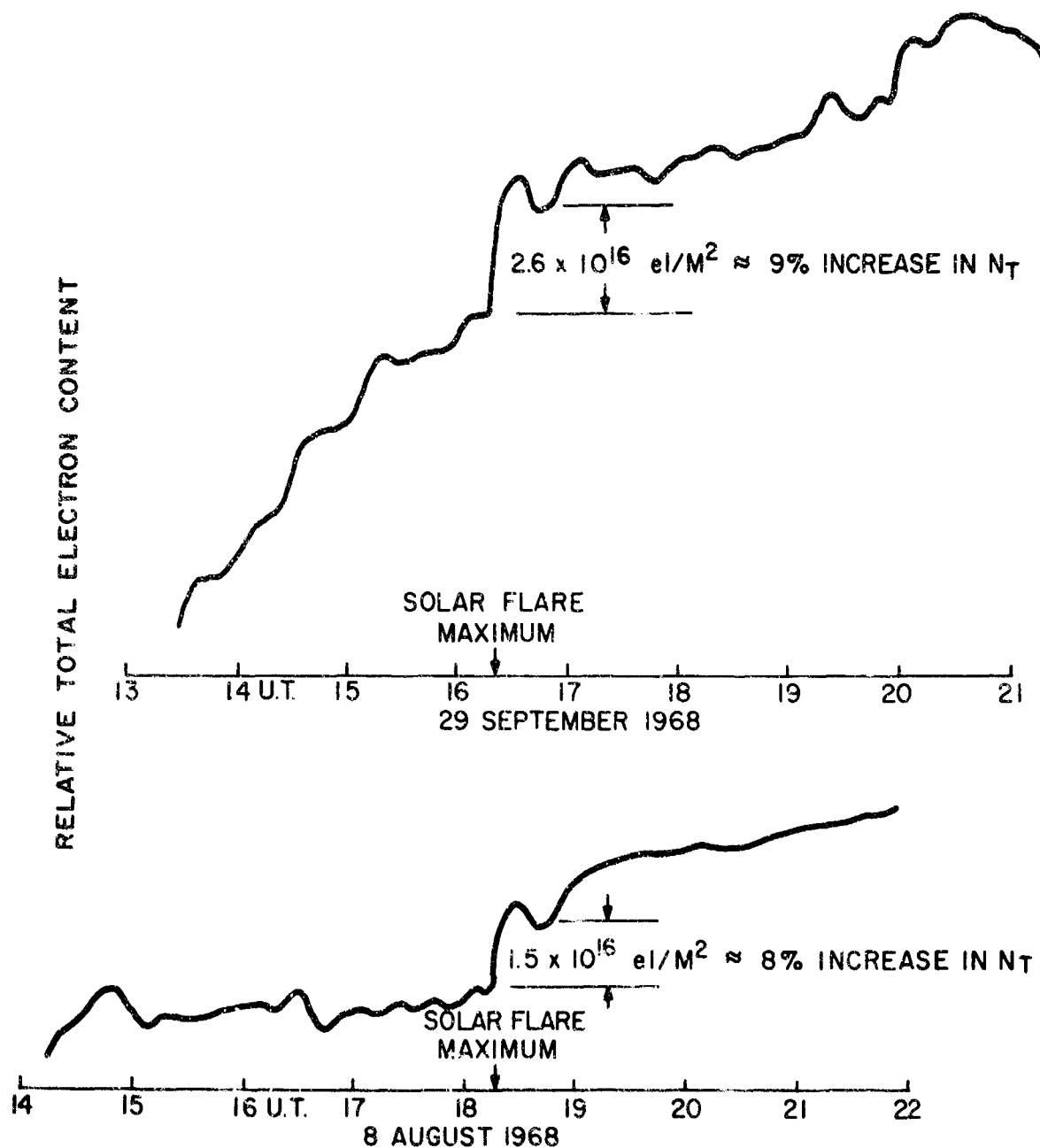


Figure 1. Fast F-region response to solar flares. Total electron content (N_T) is automatically plotted by AFCRL polarimeter.

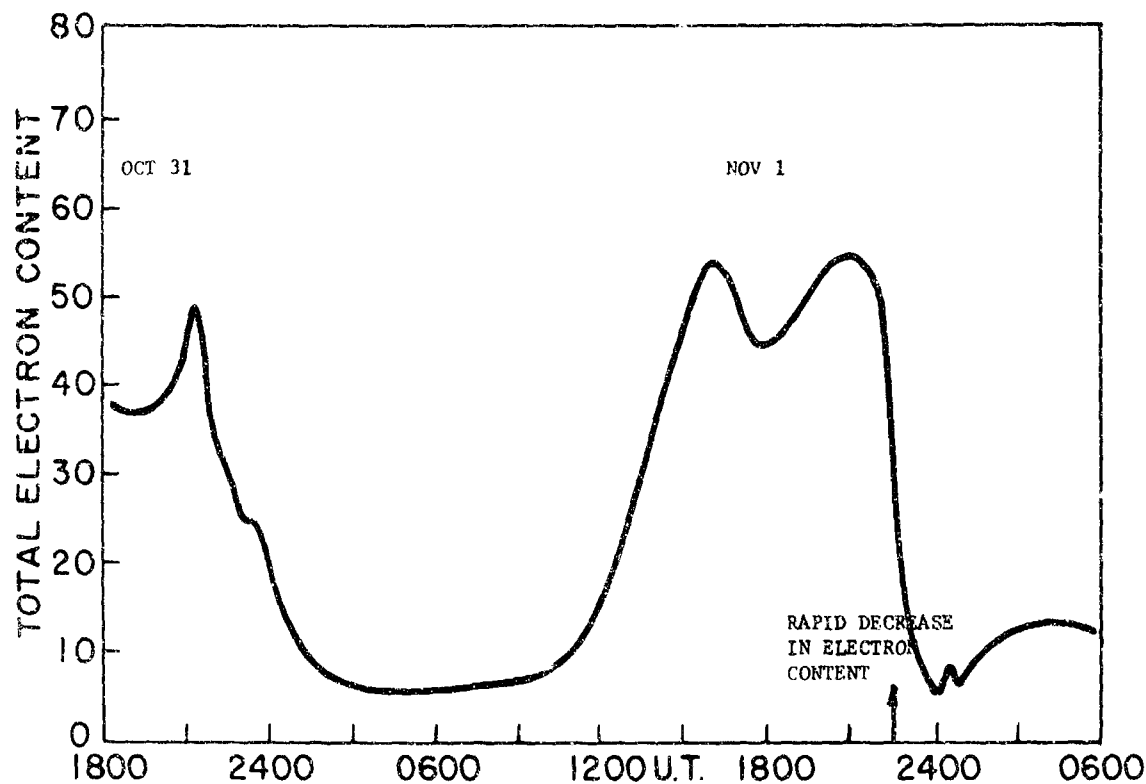


Figure 2. Total electron content variations for Nov. 1, 1968 (during a magnetic storm). 60% of the total electron content disappeared in 15 minutes.

magnetic storms on the winter and summer ionospheres. Seasonal dependence of total electron content was determined.

In addition, some predominantly winter nighttime effects were examined in detail. The total number of electrons will frequently increase in the middle of the night. Such nights show some correla-

tion with magnetic storms. The increase must be produced either by the motion of electrons from higher altitudes in the ionosphere, or by an ionizing source such as energetic electrons. The correlation of electron increases with magnetic index gives the synoptic picture; the mechanism remains to be determined.

TACTICAL WEATHER EQUIPMENT

The airborne special-operations weather teams provide support to the Tactical Air Command (TAC) and to Army field units, and also have the task of training friendly indigenous personnel in special observational techniques. These activities often require unusual observational tools and procedures. The AFCRL Aerospace Instrumentation Laboratory, through the work of Mr. Bernard D. Weiss, has developed some unique equipment for the Special Operations Weather Teams. The items constructed are small in size, simple to operate, and expendable; they are also rugged enough for paratroops and do not restrict jumper efficiency.

An expendable weather-observation kit developed at AFCRL is shown in Figure 1. This kit, weighing about three pounds (1.3 kg), contains a wind-speed sensor and wind-direction vane, a wet and dry bulb thermometer for determining dewpoint temperatures and relative-humidity values, a barometer, a rain gauge, and a clinometer for making cloud-height measurements. Also included are several hand calculators, graphs, conversion tables, and simple instructions for translating observational data into meaningful meteorological values.

Another device is the miniature helium cylinder which contains the exact amount of helium gas

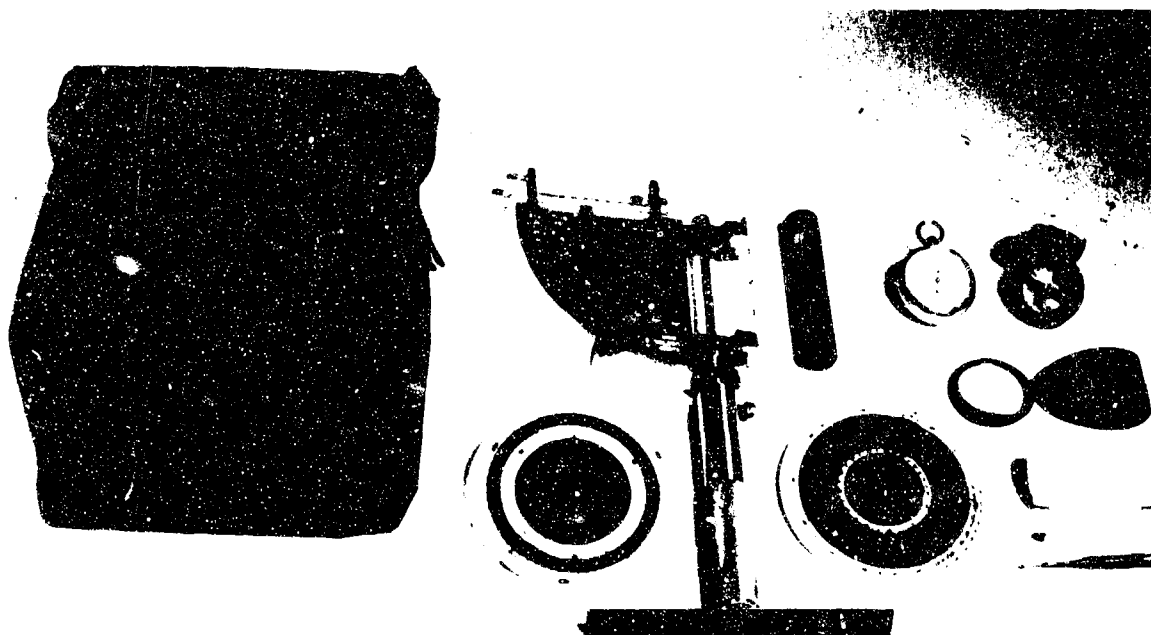


Figure 1. Expendable weather-observation kit.

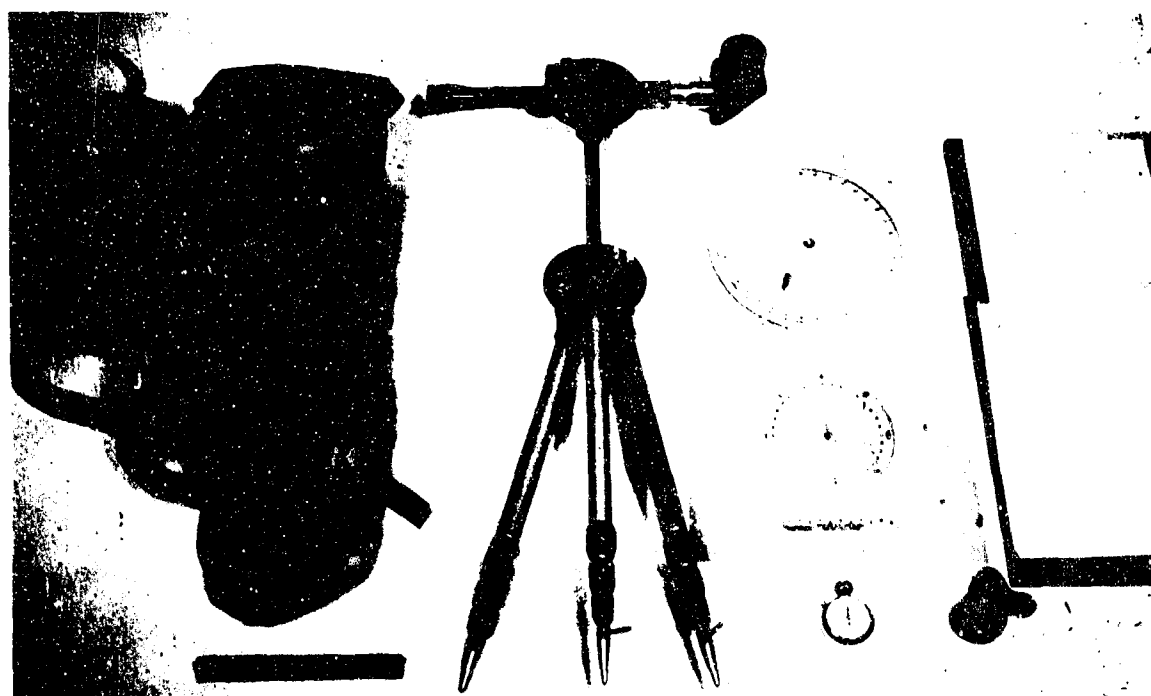


Figure 2. Miniaturized winds aloft observation kit.

needed to provide a 10-gram weather balloon with the prescribed free lift for day operations; thus the usual time-consuming weighing-off procedure is eliminated. The cylinder is 7 inches (17.8 cm) long, 2

inches (5.1 cm) in diameter, weighs 1 pound (0.45 kg), and is refillable. Eight cylinders are carried by an observer, using a webbed waist belt.

AFCRL has also developed a miniaturized kit,



Figure 3. Balloon-puncturing device.

shown in Figure 2, for winds-aloft observations. This kit, when used in conjunction with the helium cylinder kit, provides the observer with the capability for making pilot-balloon observations in remote areas. The kit contains a miniaturized theodolite, plotting board with scales, distance-out tables, compass, stop watch, and complete instructions for equipment operation and data computations. The equipment is packaged in a 5-by-13-by-20-inch (12.7-by-33.0-by-50.8-cm) carrying case; the total weight is 5 pounds (2.25 kg).

A balloon-puncturing device was designed to destroy a weather balloon automatically once the required data had been collected. This minimizes the danger that the balloon will expose the position of the observer to the enemy. The device, shown in Figure 3, consists of a small knife blade mounted on the rotating dial of a spring-wound activated timer. It weighs 0.91 ounces (25.9 grams).

All of these devices have been evaluated by the TAC weather teams and approved for use in Southeast Asian tactical operations.

PLAN SHEAR INDICATOR FOR REAL-TIME DOPPLER RADAR IDENTIFICATION OF HAZARDOUS STORM WINDS

The Plan Shear Indicator (PSI) is a new mode for the display of meteorological Doppler radar information which may prove to be valuable for the identification of hazardous winds and turbulence in storms. The PSI, developed by Graham M. Armstrong and Ralph J. Donaldson, Jr. of AFCKL, provides real-time location and the convenient highlighting of regions within precipitation echoes of abnormally large shear and spectral broadening of the Doppler velocity. The real-time capability of the PSI and its high data rate are achieved at the cost of the

mediocre resolution of ranges and velocities and the ability to measure only the shear and not the absolute value of wind components along the Doppler beam.

The PSI display for a scanning Doppler radar utilizes an ordinary PPI scope intensity modulated by a coherent memory filter. The resultant pattern is a series of concentric arcs, each one located on the scope at its appropriate range, plus an incremental displacement which depends on the radial component of velocity measured at that range. Radial shear is indicated by gaps or bunching of the arcs, while

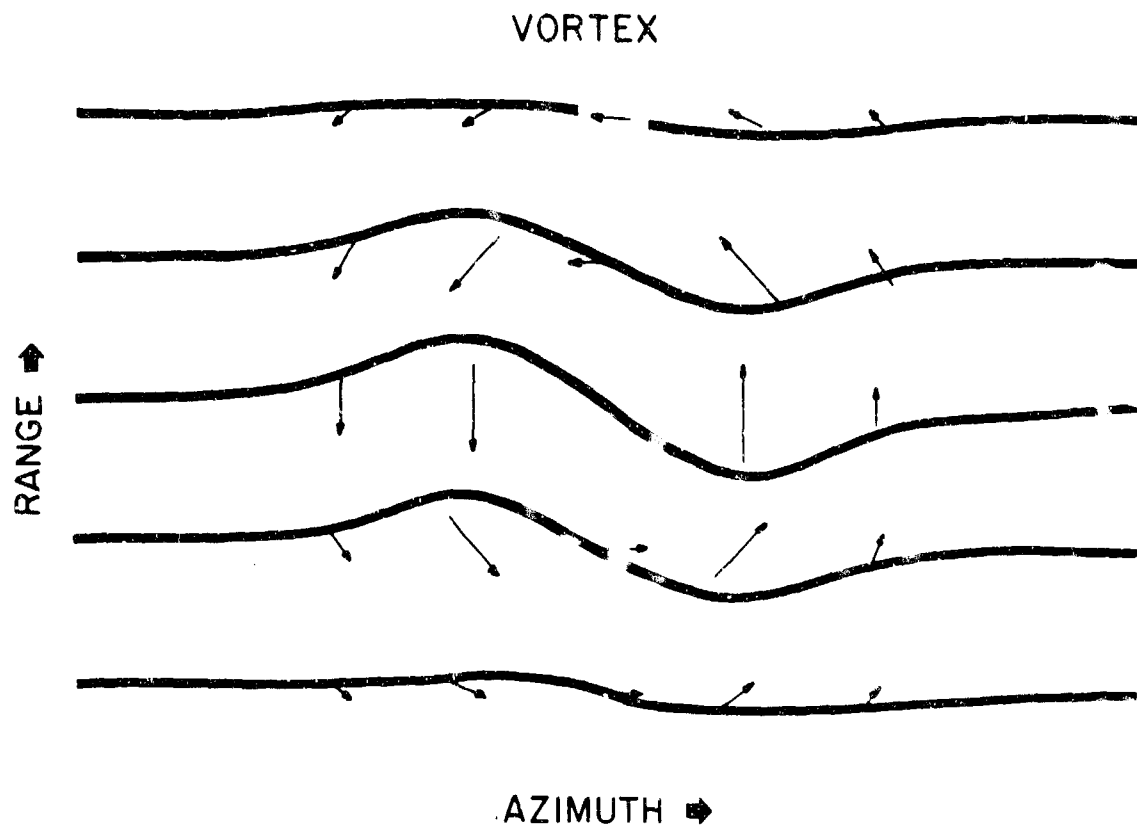


Figure 1. Schematic PSI pattern for a cyclonic vortex. Arrows represent wind vectors. Maximum vorticity is denoted by maximum arc slope, in the center of the sketch.

tangential shear, for example, a vortex, is indicated by wrinkles in the arcs as indicated schematically in Figure 1. Turbulence on a scale smaller than measurable wind shear broadens the Doppler spectrum, and is revealed on the PSI by an increase in the line widths of the arcs.

The most interesting set of storms observed to date with the PSI display occurred on 9 August 1968 when several widely scattered thunderstorms caused severe damage. Within range of the radar, one storm released a small tornado and one-inch hail; a second storm nearby was not confirmed as a tornado although it caused heavy wind damage, with hail nearly one inch in diameter; a third storm, releasing marble-size hail, struck a harbor, inflicting extensive wind damage to small boats; and a fourth storm deposited hail up to two inches in diameter, although accompanied by only minor wind damage. Figure 2 shows the PSI pattern of these storms before any wind damage or hail were reported on the ground. For convenience of description, these storms are labeled A, B, C, and D, respectively.

In all 4 severe storms, disturbances occurred in the PSI pattern for periods of 15 minutes to an hour before damaging winds or hail reached the ground. A PSI pattern suggestive of a cyclonic vortex, as sketched in Figure 1, appeared aloft in storm C. Figure 3 shows detail of the PSI pattern of storm C when the vortex configuration first appeared. Frequently the indicated vortex encircled an echo-free hole. Storm D also displayed a vortex-type PSI pattern around an echo-free hole for about half an hour before 2-inch hailstones fell on the ground. A careful tracing of the arc continuity across the hole shown in Figure 4 reveals an arc pattern which moves toward the radar with clockwise change of azimuth, suggesting cyclonic vorticity in the vicinity of the hole. Note also the very thick arcs near the hole, possibly indicating hazardous turbulence.

In summary, three applications of the PSI display are suggested by the observations of the severe storms of 9 August 1968. First, the appearance of strong wind shear aloft may provide usable warnings of the occurrence of large hail and tornadoes or other



Figure 2. Photograph of PSI Display on 9 August 1968. Letters A, B, C, and D designate severe thunderstorms as described.

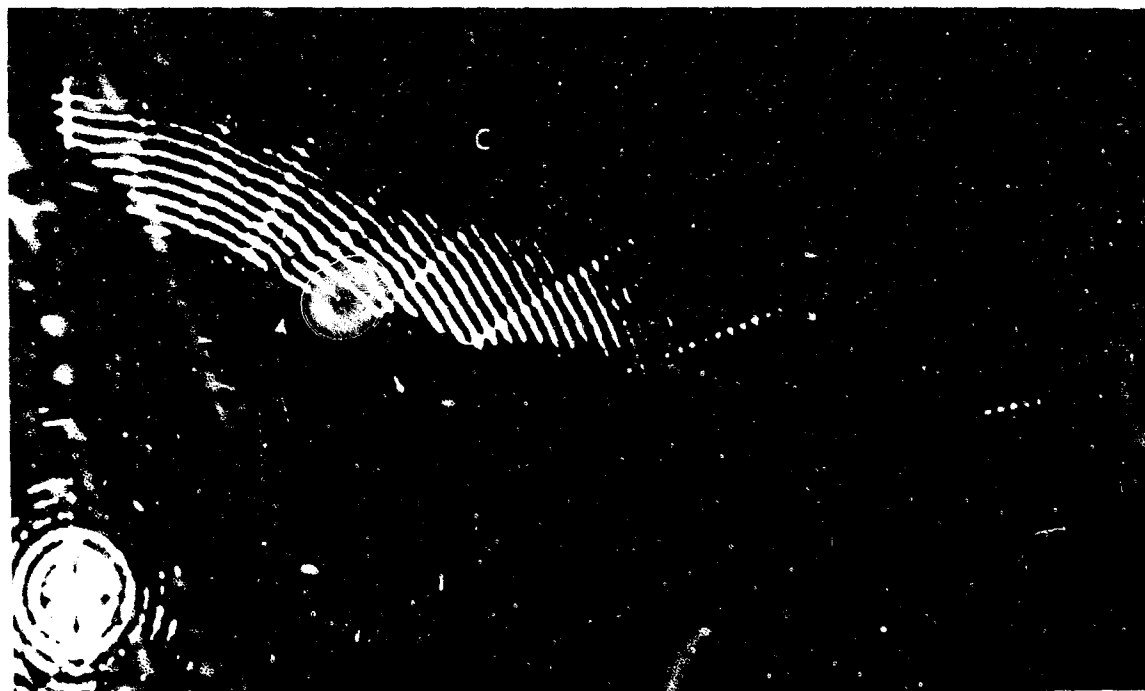


Figure 3. Detail of PSI Pattern in Storm C. Arrow points to characteristic cyclonic vortex pattern, similar to the sketch in Figure 1.

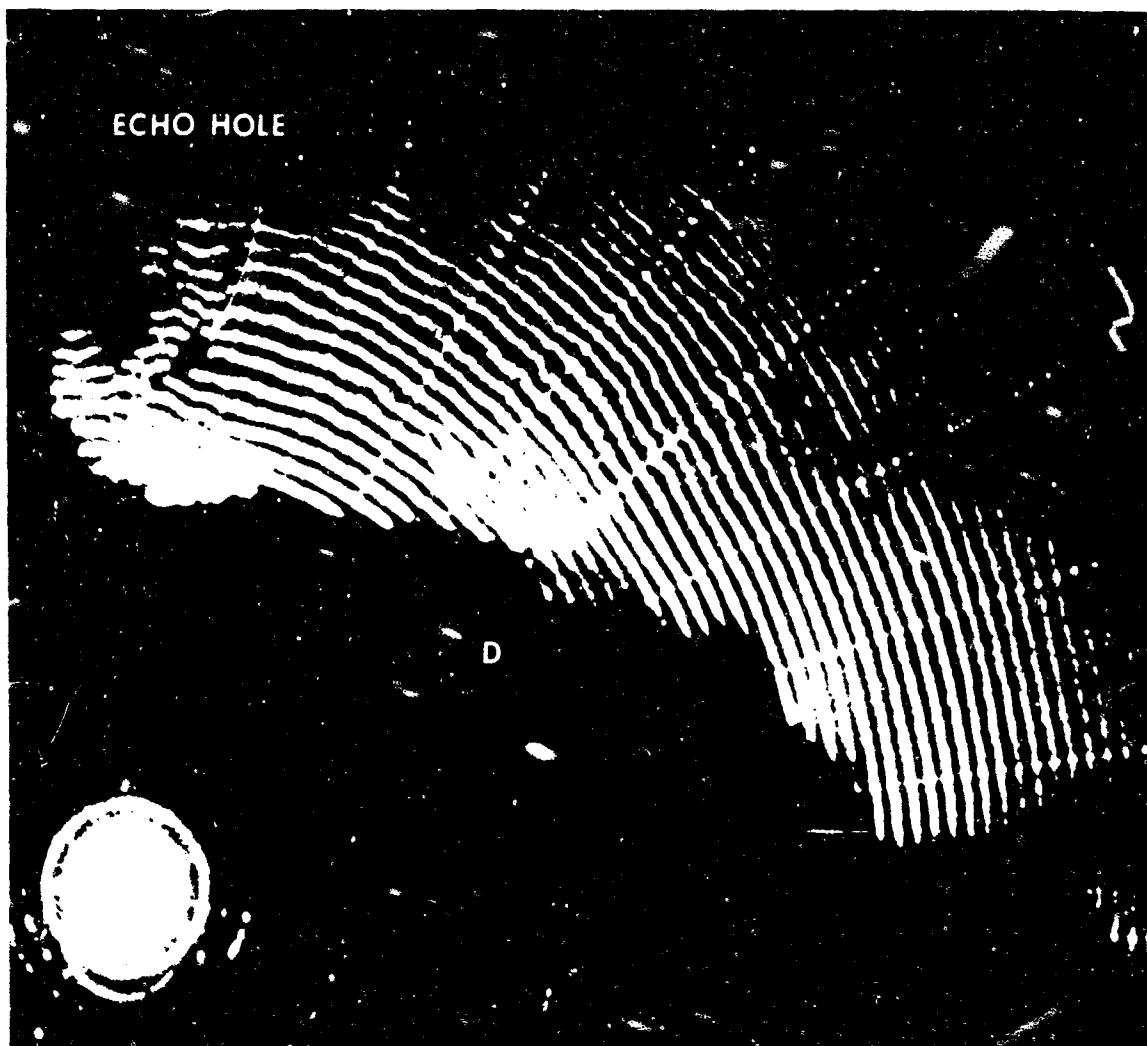


Figure 4. Detail of PSI Pattern in Storm D. Arrow points to echo hole around which the arcs curve in a manner suggestive of cyclonic vorticity.

damaging winds at the ground. The second application is real-time identification of storms, or portions of storms, in which strong wind shear and turbulence would adversely affect the safety of penetrating aircraft. If a Doppler radar with PSI display were available to an aircraft controller at a terminal, aircraft could be warned against entering an echo which would very likely be uncomfortable, if not dangerous, to penetrate. Third, the PSI display offers an opportunity for the study of air flow throughout the depth of thunderstorms, a study inspired by the appearance in two storms of patterns suggestive of vortices.

ATMOSPHERIC-DENSITY ACCELEROMETER AND LOW-ALTITUDE DENSITY SATELLITES (OV1-15 AND OV1-16)

Short-term atmospheric-density variations below 200 km have been identified as a cause of significant changes in the ephemerides of AF mission satellites and the targeting of ICBMs. However, the prediction capability for such behavior is extremely poor. Most of our present knowledge of the density of the upper atmosphere has been obtained for altitudes above 200 km from the analysis of satellite-orbit perturbations. Atmospheric-density models are relatively inadequate in the 100-to-200-km region due to the sparsity of data. Below about 200 km we do not have quantitative relations between density and solar-geophysical parameters. This uncertainty persists down to about 100 km where accurate sounding-rocket data become

available. A limited amount of density data has been obtained to as low as 150 km with the LOGACS experiment. However, this vehicle gathered data for only about 4 days. Much more information is required to develop the required density prediction capability.

A highly sensitive triaxial accelerometer system has been developed by AFCRL to gather the required data. This instrument consists of 3 single-axis, force-rebalanced electrostatic accelerometers mounted on orthogonal axes. The triaxial accelerometer system has been flown on the OV1-15 (SPADES) and OV1-16 (Cannon Ball), which are special low-altitude density satellites developed by AFCRL's Aeronomy

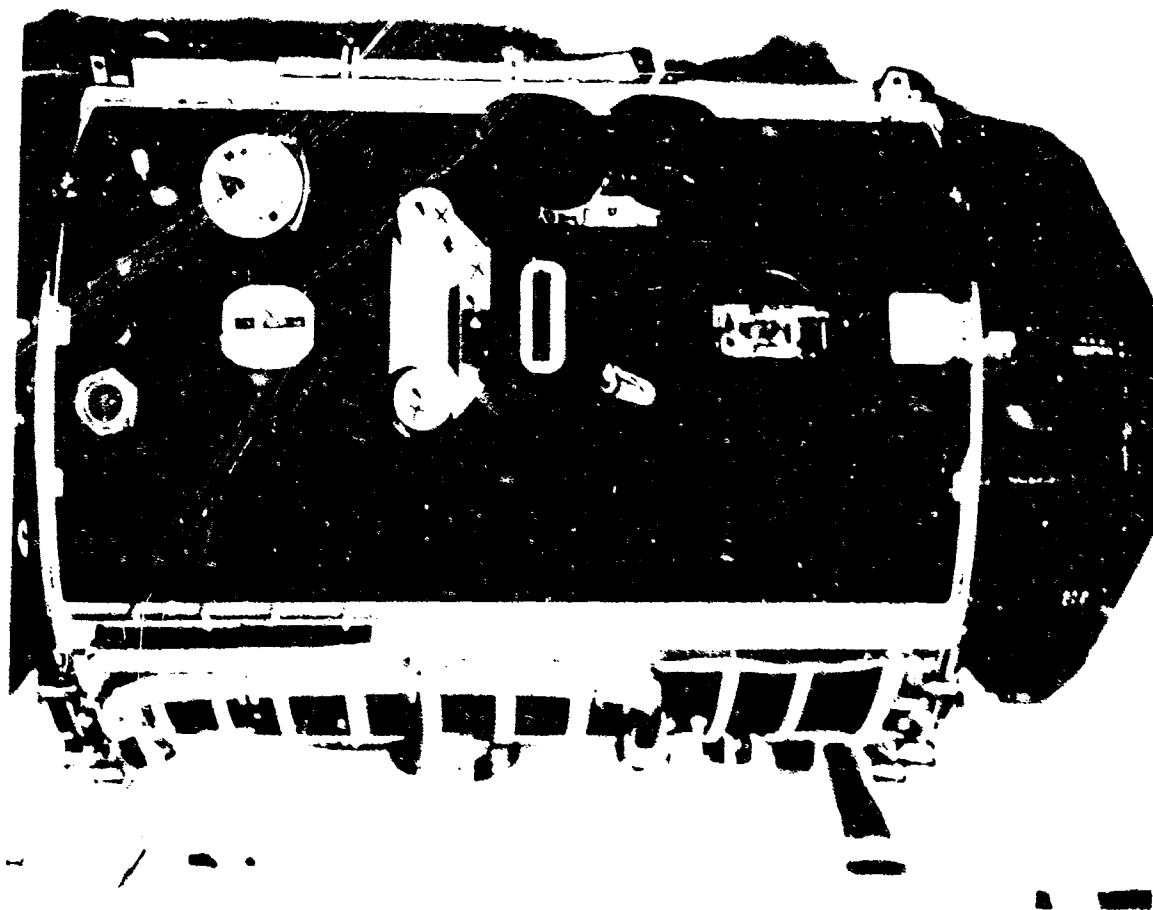


Figure 1. The SPADES (OV1-15) satellite. Overall dimensions are 54 inches long, 27 inches in diameter. The scientific experiments are in the cylindrical section, which is 32 inches long. Support systems are mounted in the approximately hemispherical domes.

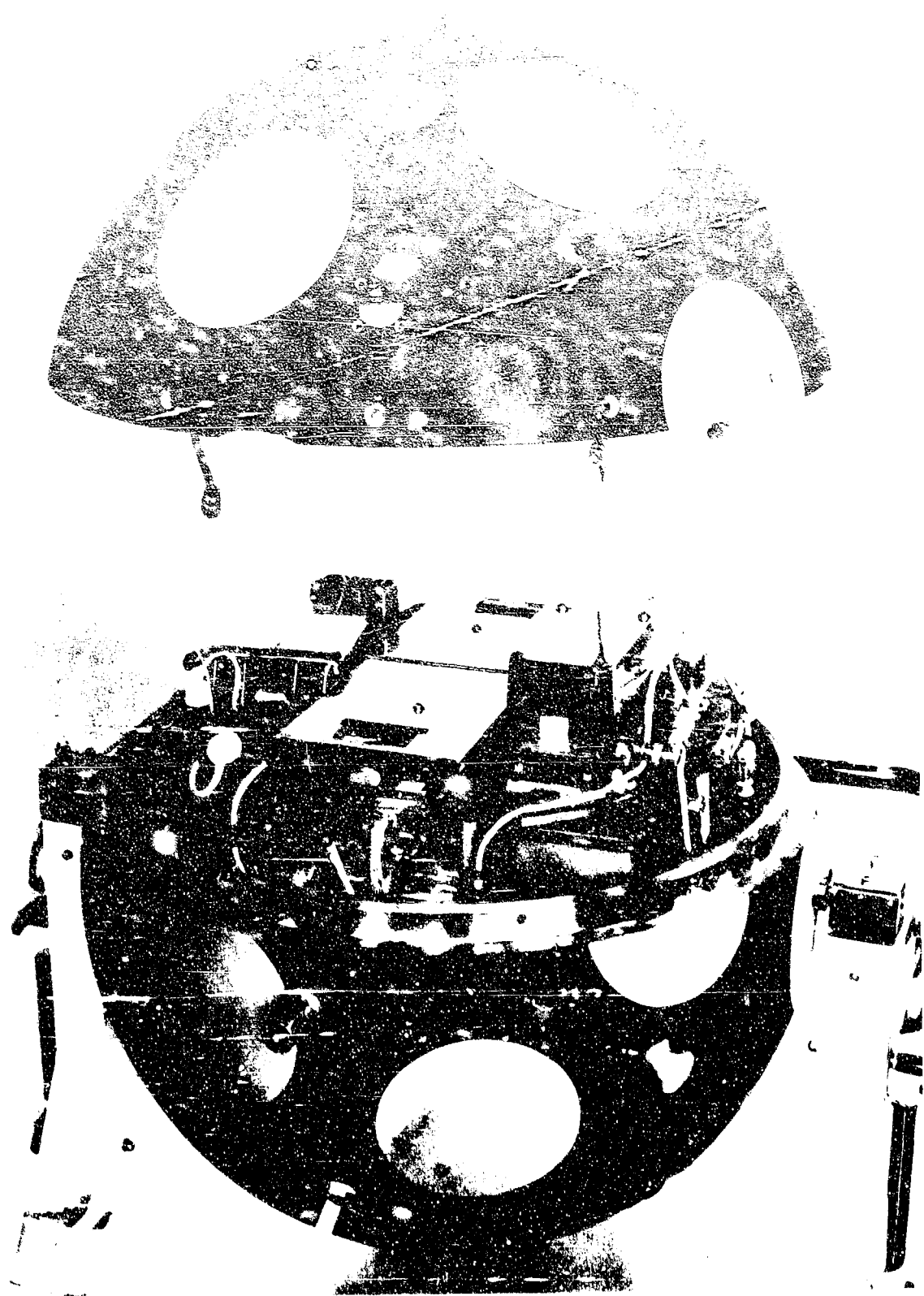


Figure 2. The Cannon Ball (OV1-16) satellite. The external shell was black with gold circles to achieve the desired thermal control.

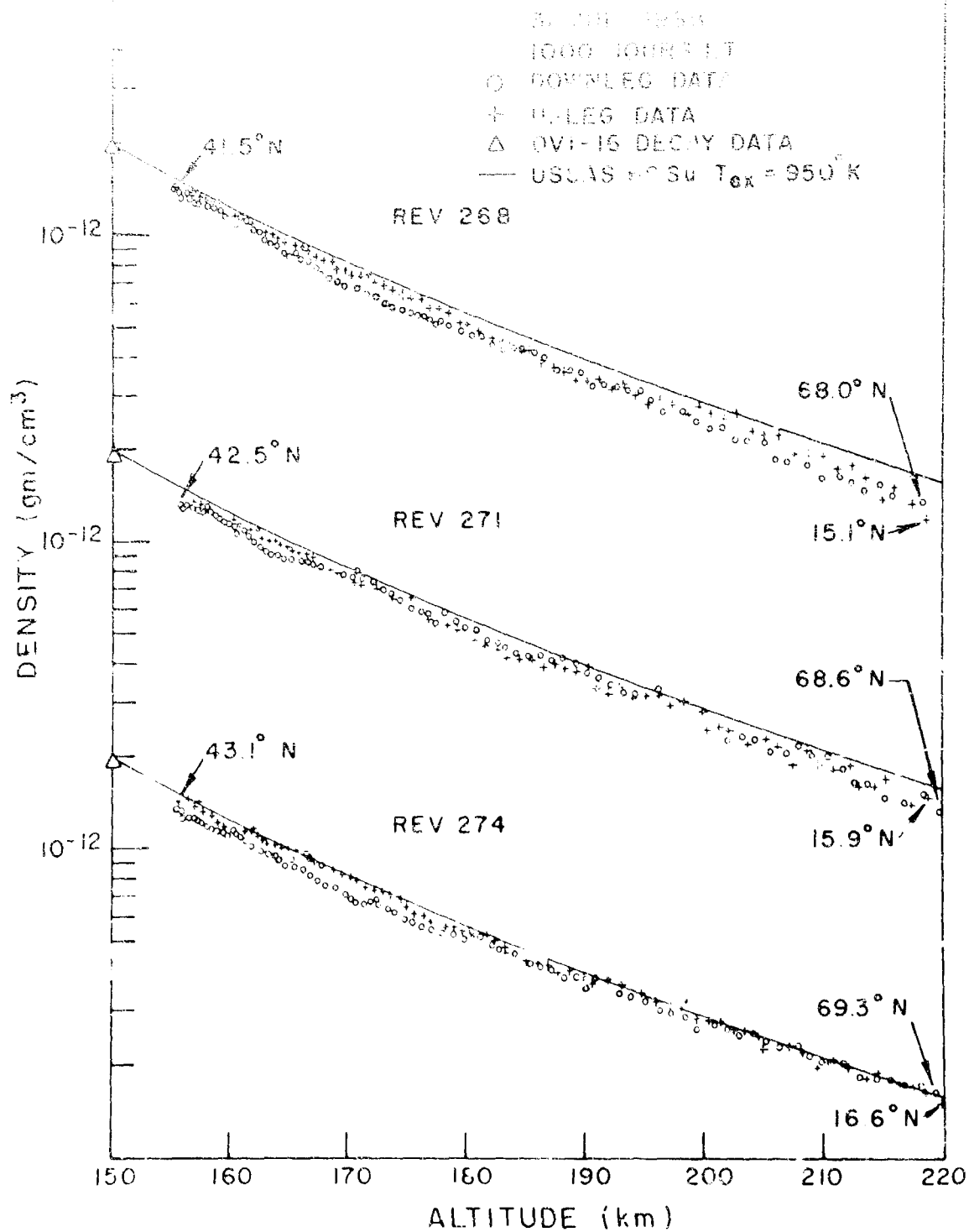


Figure 3. Three density-vs-altitude profiles obtained by accelerometers on the OV1-15 satellite. The triangle at 150 km in each case allows comparison with density data obtained from the orbital-decay technique with the OV1-16 satellite.

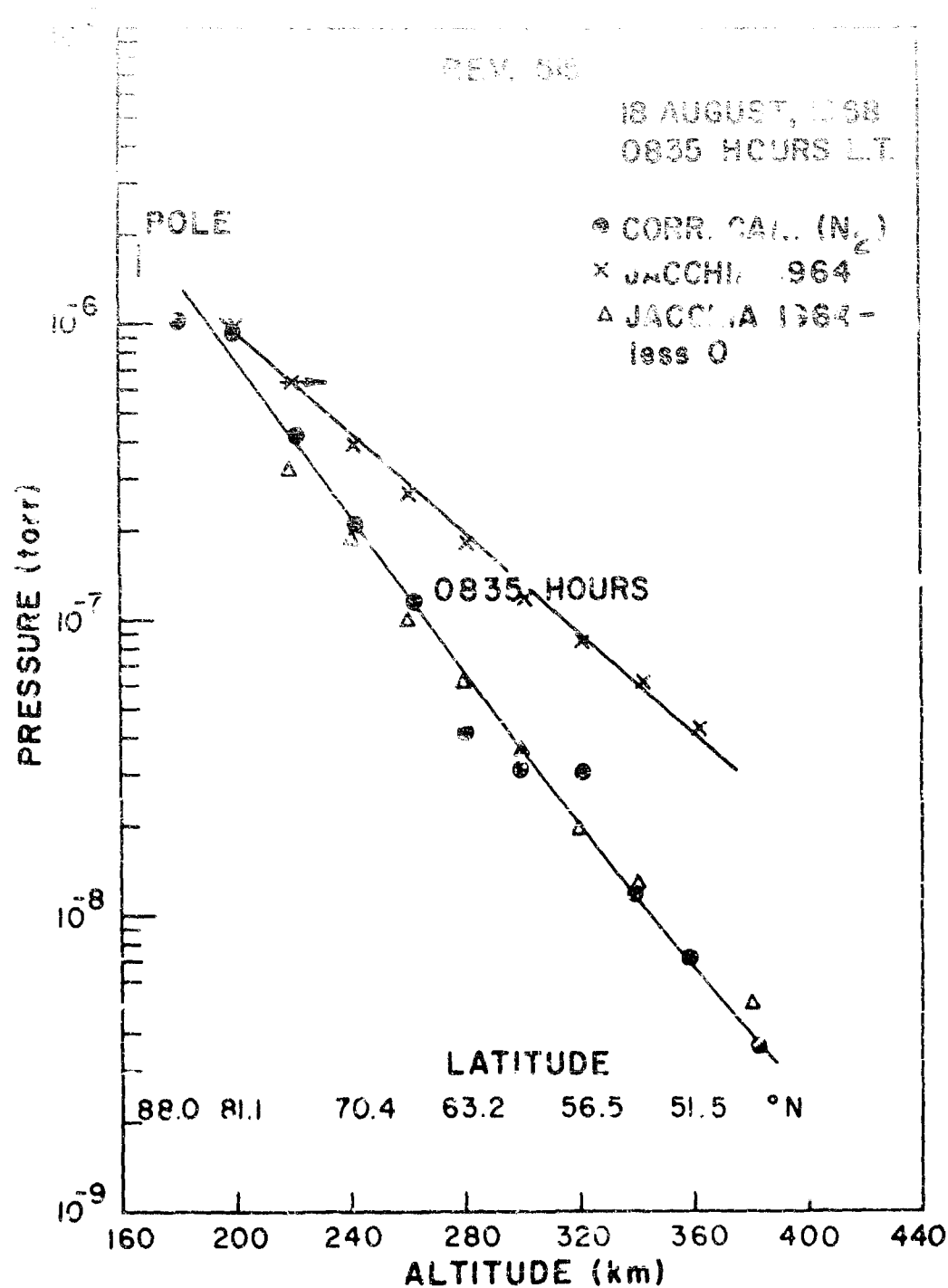


Figure 4. Atmospheric-pressure data from ionization gauge 1 on OV1-15 during revolution 515 on 18 August 1968, and Jacchia 1964 model values.

Laboratory with Dr. K. Champion as principal scientist. These satellites were launched together in July 1968. The OV1-15 satellite (shown in Figure 1), with a variety of sensors to measure density, composition, and solar radiation, was placed in an eccentric orbit

with an initial perigee of 158 km. Data were obtained in the region between about 500 km and perigee. The OV1-16 (shown in Figure 2) contains the accelerometer experiment for on-board data, and is specifically designed to obtain high-precision, low-

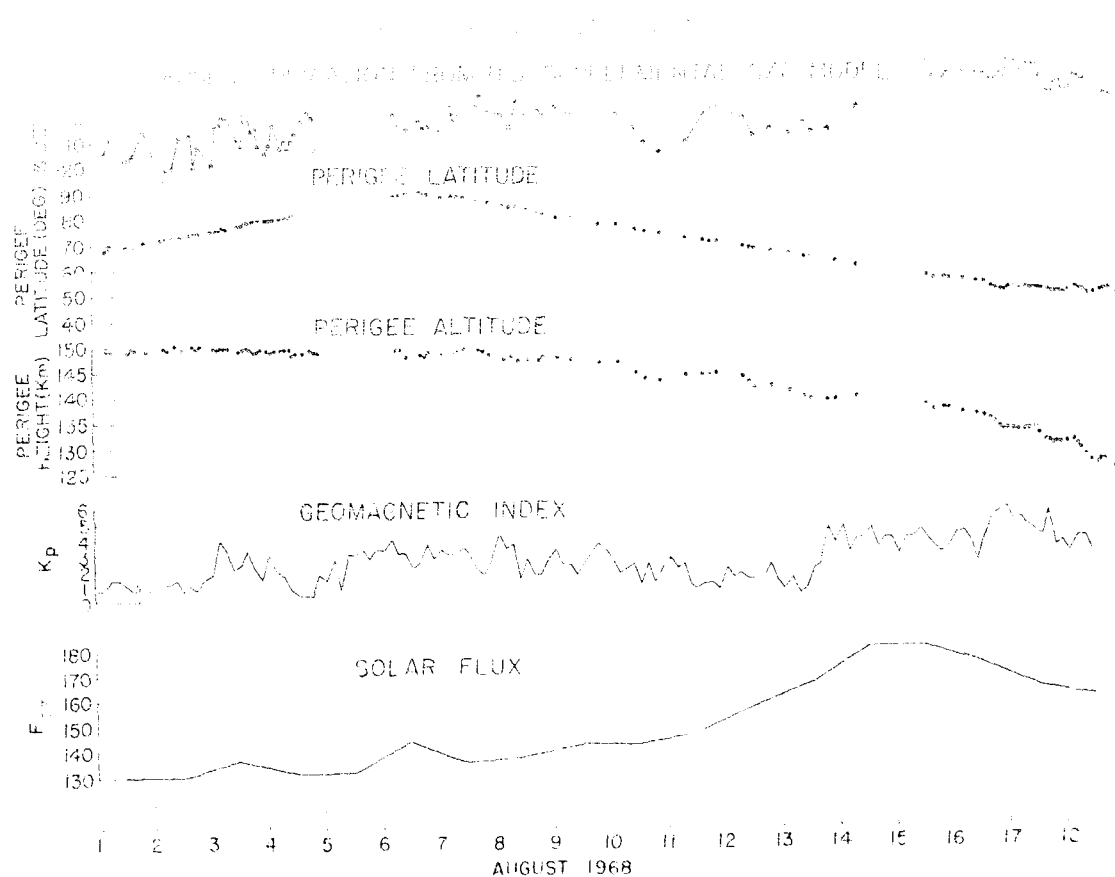


Figure 5. Orbital-drag-density deviations from U.S. Standard Atmosphere Supplements, 1966 for OV1-16, perigee latitude, altitude, K_p and $F_{10.7}$ for the period 1 to 18 August 1968.

altitude density data. Since this satellite was 5 times as dense as a typical satellite, it remained in orbit for only 39 days, but provided the first direct orbital measurements of density (or a key atmospheric property) down to 120 km.

The spherical shape minimized uncertainties in the calculation of the effective cross-sectional area and drag coefficient. Both satellites carried tracking beacons to permit a comparison of the density values obtained independently from orbital perturbations derived from tracking data, with those values obtained with the on-board instruments.

Preliminary results indicate that the density below 200 km is typically about 10% less than that predicted by most models. Figure 3 shows typical OV1-15 accelerometer data for 3 revolutions on 31 July 1968. On each orbit, data were taken between latitudes of about 68°N and 15°N . Circles and crosses represent data taken while the satellite is moving toward and away from perigee, respectively. The results are in good agreement with the appropriate

model from the *U.S. Standard Atmosphere Supplements (USSAS), 1966* (solid line).

Atmospheric pressures from an ionization gauge on the OV1-15 are shown in Figure 4. If it is assumed the gauge measures an atomic oxygen, the measured values agree well with the Jacchia 1964 model. A large block of orbital-drag data from the OV1-16 is shown in Figure 5. Density deviations from the *USSAS 66 S/F* model, perigee latitude, altitude, K_p and $F_{10.7}$ for the period 1 to 18 August 1968 are plotted. Density increases with increases in geomagnetic index and solar flux can be seen. Data analysis is continuing with the ultimate goal of achieving the ability to predict the occurrence and magnitude of short-term fluctuations and long-term changes in density in the altitude region, 100-200 km.

AIRBORNE FIELD CONTRAST ATTENUATION (SHED LIGHT)

Can an object be distinguished from its background at night? There is no easy answer to this question, since there are many factors which affect the final answer. Under the SHED-LIGHT program, the Air Force has spent considerable effort to better define this problem in order to improve capability to operate at night. The capabilities of the human visual system are being extended through a family of night vision devices, but the atmosphere, in its infinite variety of forms, acts to degrade the performance of these devices. Dr. Robert W. Fenn at AFCRL's Optical Physics Laboratory has been investigating the environmental factors affecting night vision from both the theoretical and experimental aspects.

Any object, such as a house in a rice paddy area, can be detected optically from the air only if there is a difference in the apparent light intensity from the object (house) with respect to the surrounding background (rice paddy). If such a difference exists, then a contrast is said to exist between the object and its background. As light propagates through the atmosphere, it is scattered and dispersed. Light is scattered both into, and out of, the observation path. These two factors act to reduce contrast to a level where detection may be impossible.

Light in the optical spectrum reacts differently at different frequencies or wavelengths to identical atmospheric conditions. Since both the intensity and dispersion of light are spectrally dependent, the apparent contrast, as observed at a distant point, will vary as a function of both optical bandwidth and center frequency. AFCRL's experimental program seeks to determine the contrast transmission factor, as a function of optical frequency, under a variety of nighttime atmospheric optical and meteorological conditions typical of both the Southeast Asian environment and a tropical environment of the Western Hemisphere.

Recently, Major G. J. Kline of the Optical Physics Laboratory conducted an atmospheric measurements-field program in Thailand during two 10-week periods. Data were collected during the hot dry season and the monsoon season from selected geographical locations, using a C-130 flying laboratory and a complementary mobile ground station. Aboard the aircraft were 12 optical and 7 meteorological subsystems mated to a high-speed data-recording system. Extremely low-light flux levels were measured under night-sky conditions through narrow-band spectral filters.

The aircraft flew at several altitudes over selected areas where the mobile ground station, equipped with similar optical equipment, was sited. The aircraft and ground station simultaneously collected a variety of data on the atmospheric environment. These measurements were taken under a wide range of night-sky illumination as the moon progressed through its phases. The ground station also made necessary measurements to determine spectrally the inherent contrast which the atmosphere subsequently degrades.

Three geographical areas were utilized to provide a range of representative samples of the types of atmospheric optical data which one would expect to find throughout most of Southeast Asia. These were an evergreen forested area, a rice paddy lowland area, and a seashore area. Flights were made during all phases of the moon so that a significant distribution of light intensities was obtained.

At present, the results of the two field trips are being reduced and analyzed. The program appears to have been a complete success, and preliminary results have already proven useful to the scientific community. In the near future, flights will be made in the subtropical environment of the western hemisphere to determine the extent to which results will be similar to those observed in Southeast Asia.

AIRBORNE THERMAL INFRARED SIGNAL PROCESSING

Hekla, a linear polygenetic volcano in southeastern Iceland, has had a long eruptive history. In its eruptive cycle, which began prior to 870 A.D., there have been 14 well-documented eruptions, the last occurring in 1947-48. Because most areas of thermal activity in Hekla's summit area, known since the last eruption, had not been mapped, AFCRL carried out infrared surveys over Hekla in August 1966, and again in August 1968, to determine the extent, distribution, intensity, and changes in thermal emission from

the volcano's surface over a 2-year period of repose. These observations are part of a survey program of Icelandic geothermal and volcanic areas, and comprise a cooperative effort among AFCRL, the U.S. Geological Survey, the University of Michigan, and the Government of Iceland. Dr. R. S. Williams, Jr., of the Terrestrial Sciences Laboratory, conducts the AFCRL observational program.

In the 1968 survey, AFCRL used its M1A1 airborne line-scanning system, which is sensitive to

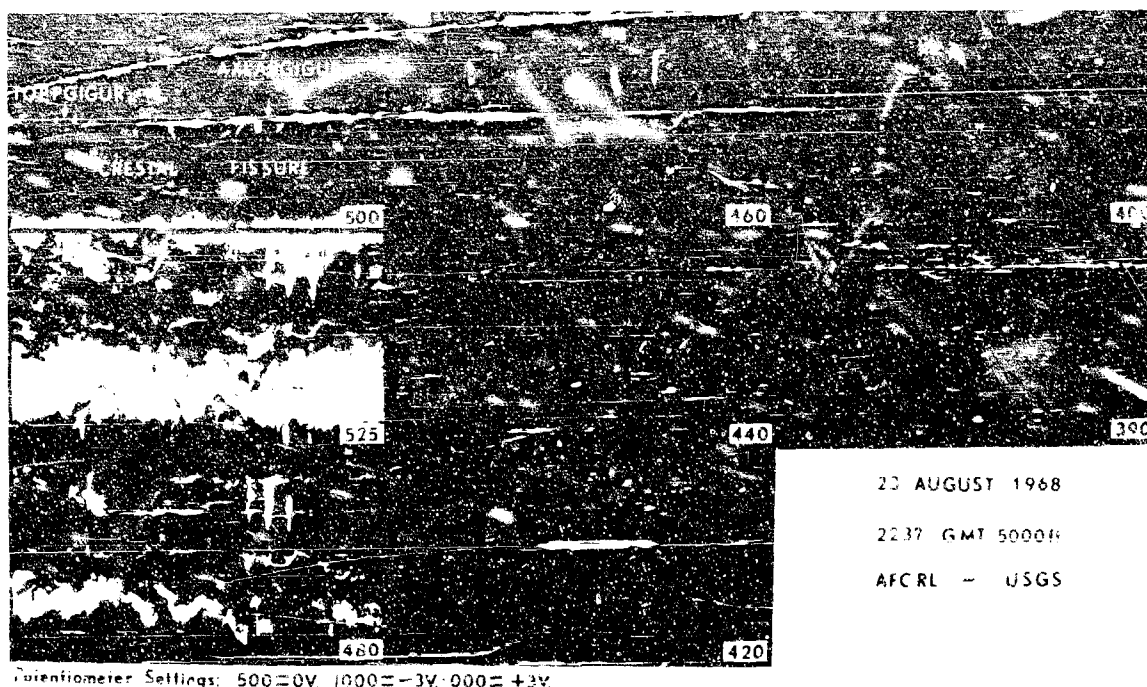


Figure 1 Signal-amplitude level slicing of thermal infrared imagery of Hekla Volcano, Iceland. Lowest potentiometer-setting imagery portrays hottest areas of thermal emission.

emitted radiation in the 4-to-5 micron wavelength band, and a special wide-band magnetic tape recorder. (The 1966 survey used the MIAI with a direct film-record system, which is limited by film-response shortcomings.) The magnetic (video) tape record permitted analysis of the returns by means of an electronic signal-amplitude slicing technique. In this technique, a threshold circuit, a 1,000-division potentiometer, and a solid-state comparator analyzed a 2.5-volt peak-to-peak input signal, and yielded an output of 11 discrete-level samples. These were printed as separate images, each correlative with increasingly intense thermal emission. Figure 1 is a series of images showing the points of the most intense thermal emission at the lower (positive signal polarity) potentiometer setting. Judging from these amplitude-level slices, maximum emission was recorded from several point sources along the inside walls of the crestal fissure (Heklugjá) between the two major craters, Toppígur and Axlargígur; these point sources are too small to have been identified either by the photographic recording method or by direct analysis of the imagery. High emission from the Axlargígur anomalies was also confirmed by the amplitude level slices.

Changes in the configuration of thermal anomalies between 1966 and 1968 were detected on the

southwest side of Toppígur; on the northeast side of Toppígur a new, but small, linear anomaly was apparent in the 1968 imagery, seemingly parallel to the northwest wall of Heklugjá. The amplitude-level technique permitted another interpretation not previously demonstrable; the highest intensity thermal sources are points and linear-to-curvilinear sources, probably fumaroles and fracture systems convecting thermal vapors to the surface. The next lower anomalies are less well-defined irregular areas, coinciding with hydrothermally altered and steaming ground.

The electronic signal-amplitude slicing technique is of value in the processing of infrared video-tape data under at least two environmental situations: in the case of surveys of geothermal or volcanic areas, the areas of highest-temperature thermal emission may be separated from a hotter-than-ambient environment, and small-diameter hot points of thermal emission may be separated from the ambient environment. In either case, the hot thermal source may be unsolvable or undetectable on direct-record thermal imagery.

ELASTODYNAMIC NEAR-FIELD OF A PROPAGATING FAULT

Although seismology has advanced remarkably in the past nine years, our basic understanding of the nature of the earthquake focal mechanism is still incomplete. An improved theory would contribute to several areas of concern to the Air Force, such as: an improvement in our ability to discriminate small underground nuclear events from low-magnitude earthquakes; the protection of surface and subsurface military installations; and protection from the results of possible hostile action on our geophysical environment.

In order to better understand the focal mechanism, Drs. N. A. Haskell and K. C. Thomson of AFCRL have been conducting theoretical calculations based on a mathematical model of an earthquake. In agreement with the narrow displacement zones actually observed on active geological faults, it is assumed that the earthquake focus can be represented as a rectangular plane sheet. The displacement is assumed to start at one edge of this sheet and propagate to the other at a finite velocity. The theory allows for the introduction of an arbitrary displacement time function, but a ramp function has been used in the calculations performed to date. In space, the displacement vector can be regarded as the vector sum of three linearly independent components. It is convenient to select these components orthogonally to correspond to well-defined types of geological faulting: (a) longitudinal shear fault; (b) transverse shear fault; and (c) tensile fault.

Earlier work involved computation of all three fault cases, but used the simplifications available for far-field calculations. Current activity involves the computation of displacement, particle velocity, and acceleration wave forms at points very close in to the fault for all three types of fault mentioned above. The results for the case of a longitudinal shear fault

were obtained and compared with the observed accelerations on the Parkfield earthquake. The assumed source displacement function was obtained by summation of ramp functions. The resulting theoretical horizontal acceleration component, transverse to the fault and at a very close-in point, is shown in Figure 1. The corresponding observed acceleration component for the Parkfield, California earthquake of June 1966 (as observed at the nearest station to the fault on the strong motion array at Cholame, California) is compared with theory in the upper portion of Figure 1.

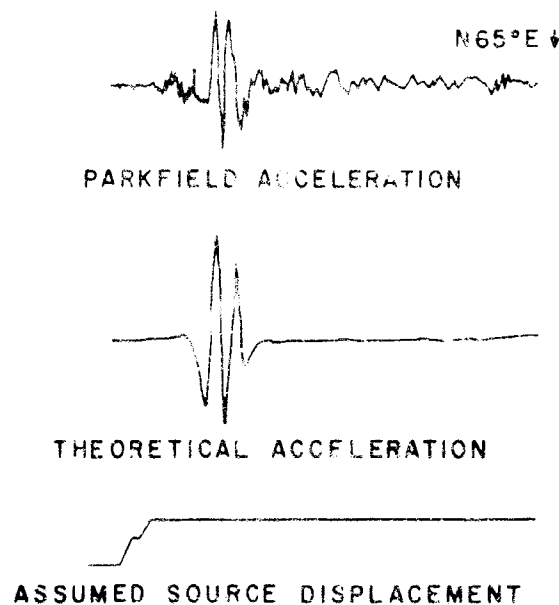


Figure 1.
Strike-slip source theory vs. Parkfield earthquake observations.

POLAR-CAP ABSORPTION STUDIES

The predicted maximum of solar activity for the present solar cycle is 1968-69. Huge flares and prominences that periodically erupt from the sun occur most frequently during this period. The high flux of charged particles and X rays from these flares can have pronounced effects on the earth's environment. The most serious effect is caused by high-energy protons from the sun deflected towards the polar regions by the earth's magnetic field and creating a condition known as polar-cap absorption (PCA)—or polar-cap blackout. Increased ionization in the lower ionosphere by these particles causes a severe absorption of HF radio waves. The attenuation

of these signals propagated across the polar regions may persist for several days, degrading the performance of Air Force communications, navigation, and detection systems using these frequencies.

From August through November 1969, AFCRL conducted an extensive study of the polar-cap absorption phenomenon using rockets, aircraft and ground-based measurements. One phase of the rocket research involved the launching of several Black-Brant rockets by the Ionospheric Physics Laboratory at AFCRL. These rockets, launched simultaneously with others from AFCRL's Aeronomy Laboratory were flown at night, during the day, and at sunrise and

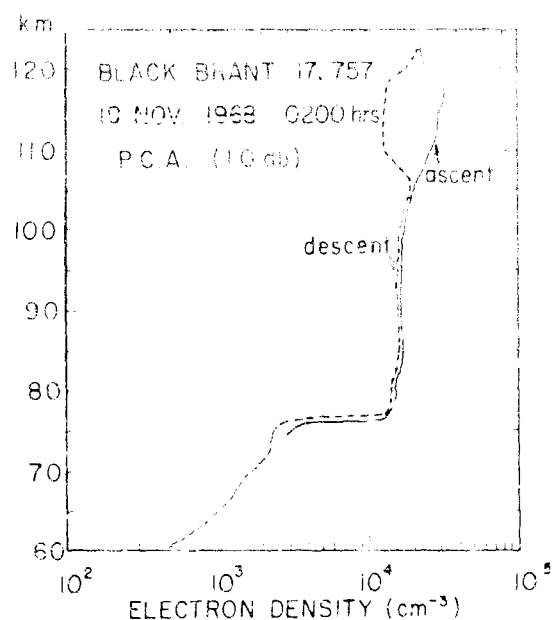


Figure 1. Electron density as a function of altitude measured on 19 November 1968 at 0200 hours during the PCA at Churchill, Canada.

sunset for the study of the physical chemistry of the D region of the ionosphere.

To certify the Black-Brant payload and to obtain vital preliminary information on the ionospheric parameters during a PCA, a Black-Brant rocket was

prepared for launching at the Churchill Research Range, Manitoba, Canada, in October 1968. On 18 November 1968 a PCA occurred, and the rocket was successfully launched at 0200 hours on 19 November. This rocket, in addition to being the first one ever successfully flown at night during a PCA event, had the most comprehensive payload launched to date for the study of the D region of the ionosphere. The rocket contained experiments for the measurement of protons (1-100 MeV) and Alpha particles (3-250 MeV); electron density and temperature; ion density; temperature and mobility; Lyman Alpha flux; photometric measurements of N_2^+ , Hg, O, and NO_2 continuum; X-ray flux (1-10 KeV); and total energy deposition (electrons $E > 10$ KeV and protons $E > 100$ KeV).

Of the data analyzed to date, the most significant measurements were the electron density and temperature. Ionization was found as low as 55 km, with densities as much as 3 orders of magnitude higher than normal nighttime values at certain altitudes (Figure 1). Accompanying the high ionization were abnormally high electron temperatures for these regions. These data, in addition to the other measurements, are being studied in regard to the physical chemistry in the D region and the absorption of radio waves in the ionosphere during a polar-cap blackout. The initial results were presented at the International Space Science Symposium (COSPAR), in Prague, Czechoslovakia, on 21 May 1969. The *Proceedings* of the Symposium will be published in the spring of 1970.

ATMOSPHERIC MOTIONS DEDUCED FROM SMOKE TRAILS

Atmospheric motions at altitudes of 30 to 60 km (100,000 to 200,000 ft) may appear as turbulence to advanced aerospace systems, for example, a hypersonic lifting reentry aircraft flying at 3 to 6 km/sec (6,800 to 13,600 miles per hour). The Aerospace Instrumentation Laboratory at AFRL has made some progress in exploratory research directed toward providing estimates of atmospheric motions in this altitude region.

In an exploratory experiment, conceived and directed by Mr. Robert Lenhard of AFRL, a series of 4 spatially separated smoke trails were placed simultaneously at altitudes between 30 and 70 km (100,000 to 230,000 ft). Observations of these trails provided data for temporal and three-dimensional

spatial analyses. Figure 1 is an example of smoke-trail behavior as viewed from one angle.

A preliminary study of these data by Major James Marshall of AFRL dispelled the previously held concept of many scientists that the thermally stable stratosphere is quiescent. The study shows smoke trails to be good sensors of atmospheric motions, and indicates that vertical motions are present at all levels between 30 and 70 km. Vertical motions greater than 5 m/s (11 miles per hour) and probably as great as 15 m/s (34 miles per hour) are present even below the stratopause.

Upon completion of data reduction, it is hoped that space and time analysis of the entire experiment

will produce an acceptable and useful theoretical model of these atmospheric motions. At present, we

can only speculate about possible causes and their significance for aerospace vehicles.



Figure 1. Simultaneous smoke (trimethyl-aluminum) trails over the Gulf of Mexico photographed in evening twilight on 29 Nov 1967 from a camera site near Eglin AFB, Fla. The trails are approximately 17 km apart, centered near 50 km, and visibly extend from near 35 km to 70 km. The horizontal displacement in the distortion near the top of the trail is roughly 2 km in length. The trails were retouched for reproducibility.

SOLAR-FLARE FORECASTING FROM MILLIMETER-WAVE OBSERVATIONS

Observations of the sun have been conducted for many years in an effort to unravel the physical nature and origin of the solar atmosphere, and to investigate the mechanism of the solar-induced terrestrial effects such as aurorae, HF communication blackouts, and magnetic storms. With the realization of man-in-space programs, one particular solar effect, the proton flare, has become especially important because of the biological hazard it presents to astronauts in earth-orbiting space vehicles.

As part of AFCRL's program to provide fundamental data leading to a capability for solar-flare forecasting, Mr. P. M. Kalaghan of the Microwave Physics Laboratory has been making high-resolution observations of the sun at 8.6 mm. At this wavelength, the radiation originates primarily from the upper and middle chromospheric regions. The program includes daily mappings of the black-body temperature distribution over the solar disk. Active centers appear as local enhancements in the observed intensity distributions. (The observed frequency of occurrence of these enhancements is shown in Figure 1.)

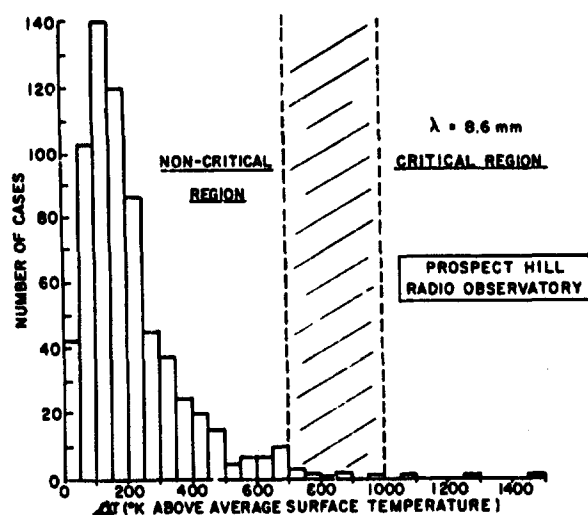


Figure 1. Frequency of occurrence of active regions (Feb. 1968-Oct. 1968).

Analyses of the millimeter-wavelength observations show that active regions exhibit black-body temperatures as high as 25 percent above the quiescent background levels, with typical enhancements lying between 5 and 10 percent; these regions are associated in position with the underlying plage

regions. Of particular interest are the temporal variations of the active regions as they pass across the solar disk. They exhibit two distinct time scales. The first type, or slow variation, occurs over periods ranging from several hours to a few days, with 50-percent decreases to 100-percent increases in the level of enhancement. The second type, the burst variations, last only a few minutes. Bursts have been seen only in those regions exhibiting at least a 6-percent level of enhancement, and for which there has been an optical event taking place simultaneously. These burst variations have usually produced an order-of-magnitude increase in the intensity levels; but, because of the small size of the brightened region, such bursts have increased the total solar flux by only a few percent. However, exceptions have occurred during proton-producing burst events where increases comparable to the total solar flux have originated from regions with an area of less than 1 percent of the total solar disk. For example, in one case the intensity of a burst produced an 82-percent increase in the solar flux at a wavelength of 8.6 mm.

To provide some measure of the potential activity of a particular region, based on its 8.6-mm enhancement, 3 distinct levels of enhancement have been defined. The "mildly active" are those exhibiting enhancements of 5 percent or less; the "moderately active" are those with enhancements from 6 to 13 percent; while the "critically active" are those with enhancements greater than 13 percent. (In all cases, the classification of a region is determined by its steady-state or stable intensity level rather than from an elevated level that may occur during a burst event.) With this classification of areas, the life histories of individual regions can be described and their potential assessed.

These high-resolution observations at a wavelength of 8.6 mm have demonstrated their utility as a means of gathering new data on active centers. Of particular importance is the suggestion that a "critically active" enhancement is a necessary, although not sufficient, condition for the occurrence of a proton event from a particular center of activity.

THE ATMOSPHERE OF THE PLANET VENUS

Venus, the sister planet of Earth, has frustrated astronomers in their efforts to discover the constituents of the Venusian atmosphere and the physical conditions existing on the planet's surface. The chief obstacle has been the continuous cloud cover which has allowed the planet to literally remain "shrouded in mystery."

Recently, a method of probing the atmospheric constituents of the planet Venus, using phase-effect observations, was investigated by P. M. Kalaghan of AFCRL's Microwave Physics Laboratory. Measurements at 3 wavelengths (3.15 cm, 0.86 cm, and 0.34 cm) indicate that the illuminated and unilluminated hemispheres of the planet emit radiation equivalent to a black body at the following temperatures (see Figure 1):

Radiometric Temperature		
Wavelength	Illuminated Hemisphere	Unilluminated Hemisphere
3.15 cm	694 °K	448 °K
0.86 cm	435 °K	415 °K
0.34 cm	285 °K	307 °K

Of particular significance is the fact that the 0.34-cm data indicate that the night side of the planet appears warmer, radiometrically, than the sunlit face, while just the opposite is true at the other two wavelengths. Thus, significantly different physical conditions must exist on the two faces of the planet; otherwise, they would both exhibit similar spectral characteristics.

If one defines a model atmosphere compatible with the status of current knowledge of the planet (i.e., atmosphere with 75%-90% CO₂ and the remainder N₂), and a variable surface temperature, it should be possible, utilizing the theory of radiative transfer, to theoretically predict the spectral behavior of the radiometric temperature exhibited by the planet. However, gross disagreement with the observational data resulted, indicating that the "normal" atmospheric models are inadequate and that there must be some additional significant constituent within the atmosphere.

Interestingly, in 1961, E. J. Opik had suggested the existence of a heavy distribution of dust, or haze, in the lower atmosphere which was kept aloft by winds over the hot arid surface of the planet. Since dust particles interact with centimeter- and

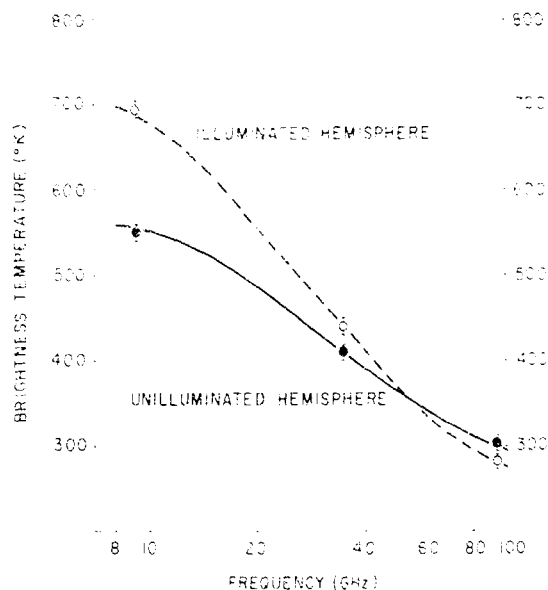


Figure 1. Brightness temperature of Venus as a function of frequency.

millimeter-wavelength radiation, the incorporation of a distribution of dust into the model atmosphere was attempted at AFCRL; it was shown to produce a spectral response in agreement with the measured data, as shown in Figure 1. Thus, a strong possibility for the missing constituent in the Venusian atmosphere is planetary dust, perpetually falling and then being raised from the surface by air currents existing over the very hot surface. Furthermore, it was found that the day face of the planet must exhibit a surface temperature of about 820 °K, while that of the night face must be some 200 °K lower. The distribution of dust is physically compatible with this notion of differing surface temperatures, in that the dust distribution on the hotter face is heavier and more extensive than on the cooler face, as would be expected from consideration of the air currents on each face. Thus, the utilization of ground-based observations over the 3-cm-to-3mm-wavelength range provides a new insight into the Venusian atmosphere, and offers promise for probing other planetary environments.

DEGRADATION OF RUBY-LASER OUTPUT

In the course of extensive tests of ruby-laser rods of different sizes and origins, Dr. C. M. Stickley and his coworkers at AFCRL's Optical Physics Laboratory observed that the energy output of one was considerably less than that of three others similar in size and in Cr^{3+} concentration, and that the original low-threshold energy of two other rods degraded after they were fired only a few times. Gradual reduction in output energy during repeated firing also occurred with varying degrees of severity in all ruby rods tested. Because output energy that gradually declines from shot to shot is undesirable in practical, as well as experimental, applications of lasers, AFCRL made an intensive study of this effect.

The degradation was traced to the formation of color centers within the ruby rod. Color centers in the rod absorb pump light, and depletion of the pump-light energy density correspondingly reduces the laser-energy output. Repeated firing of the laser causes more and more color centers to be created and

results in a steady degradation of the laser-output energy.

The identification of color centers as the cause of degradation was made by comparing curves of absorption vs. wavelength for ruby (Cr_2O_3 in Al_2O_3) with curves for clear sapphire (Al_2O_3 containing no Cr_2O_3) in which color centers had been artificially induced. As Figure 1 illustrates, the shapes of these curves agree, showing that absorption by color centers occurs. (It also shows that these centers are properties of clear sapphire, and do not require the presence of Cr^{3+} ions for their formation.)

The identification was substantiated by theoretical calculations. Electrons, initially bound to atoms in the crystal, absorb sufficiently high-energy photons from the pump light so that they are raised to the conduction band of Al_2O_3 . From the conduction band, an electron can either return to the bound state in an atom, or it can drop into a vacancy in the crystal lattice. If it goes into a vacancy, a color center

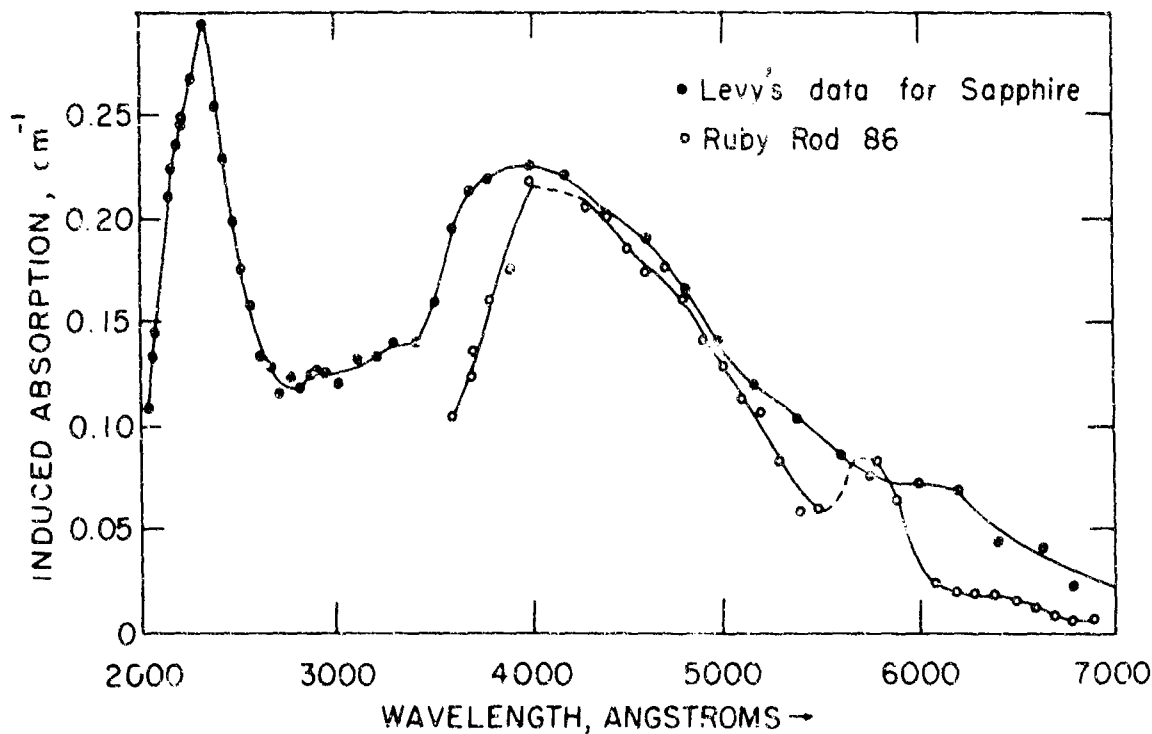


Figure 1. Absorption induced in ruby by the pump light and in clear sapphire by low energy γ rays.

is created; the electron in this vacancy can absorb light and, by so doing, it "colors" the crystal. The degree of pump-rate reduction expected from the absorption caused by formation of these centers was computed. The results of the calculation and the experiments agreed to within the experimental error.

The source of the electrons that fill the vacancies is not known; the observations show that Cr^{3+} plays essentially no role in this process. Impurity analyses of selected samples showed that impurities are pres-

ent in the amounts of 500 to 5,000 parts per million. This is equal to 1 to 10 times the amount of Cr^{3+} present in a 0.05% ruby rod.

The principal contribution of this study is that one mechanism out of numerous possible ones has been identified as being responsible for the output-energy decay. The complete solution to this problem will be achieved when we understand how to prevent the formation of color centers in pure sapphire.

ground electronics

RESEARCH ON SPEECH PROCESSING

Measurement of the degree of fidelity of reproduced speech is one of the main problems in research on speech processing. The speech intelligibility, its quality and naturalness, and the degree to which familiar voices can be recognized by a listener after the speech signal has been processed, are of particular concern for rating and evaluating devices for narrow-band digital voice communications, such as vocoders. Studies of these problems also support longer-range objectives, for example, the evaluation of techniques for permitting a computer to "speak"—that is, to generate its response in an intelligible voice message.

One of the results of the program of the AFCL Data Sciences Laboratory is a new method for testing speech intelligibility, the Diagnostic Rhyme Test (DRT). The attributes, "voicing," "nasality," "sustention," "sibilation," "graveness," and "compactness" are the fundamental features by which we perceive and recognize speech. The DRT test measures the degree of accuracy with which each of these fundamental components of intelligibility are perceived by a listener. Thus, it provides a score for total speech intelligibility and a diagnostic profile that pinpoints the particular deficiencies of a speech-processing technique or device. This new test has been employed in two major research efforts which have yielded new insights into speech-processing technology.

The first of these undertakings was a survey of the "state-of-the-art" of vocoder technology, which was organized by C. P. Smith of AFCL and involved the cooperative effort of industry, the universities, and professional societies. The DRT was used to obtain performance ratings on representative vocoder systems operating at 2,400 bits per second. The results are demonstrated in the performance profile of Figure 1, which presents the average, best, and poorest scores obtained in this survey for each of the six components of speech intelligibility, as well as for the total intelligibility. The vocoders' poorest performance was for the feature, "sustention." This is the feature that distinguishes the short, abrupt consonant sounds from their sustained counterparts, that is, "p" from "f," "th" from "t," and "v" from "b." Considerable bias for the intelligibility of this feature was revealed. The negative state of this feature, which characterizes the abrupt consonants, showed an average intelligibility of only 77%, while the best system tested only obtained a score of 84%. For the positive state of this feature (the sustained consonants), the average score was 88%. The next poorest feature was "graveness" (the grave-acute opposition), which distinguishes "p" from "t," "b" from "d," and "m" from "n." The performance-profile chart provides a valuable benchmark in speech-processing technology, both by pinpointing

SPEECH INTELLIGIBILITY DIAGNOSTIC PROFILE

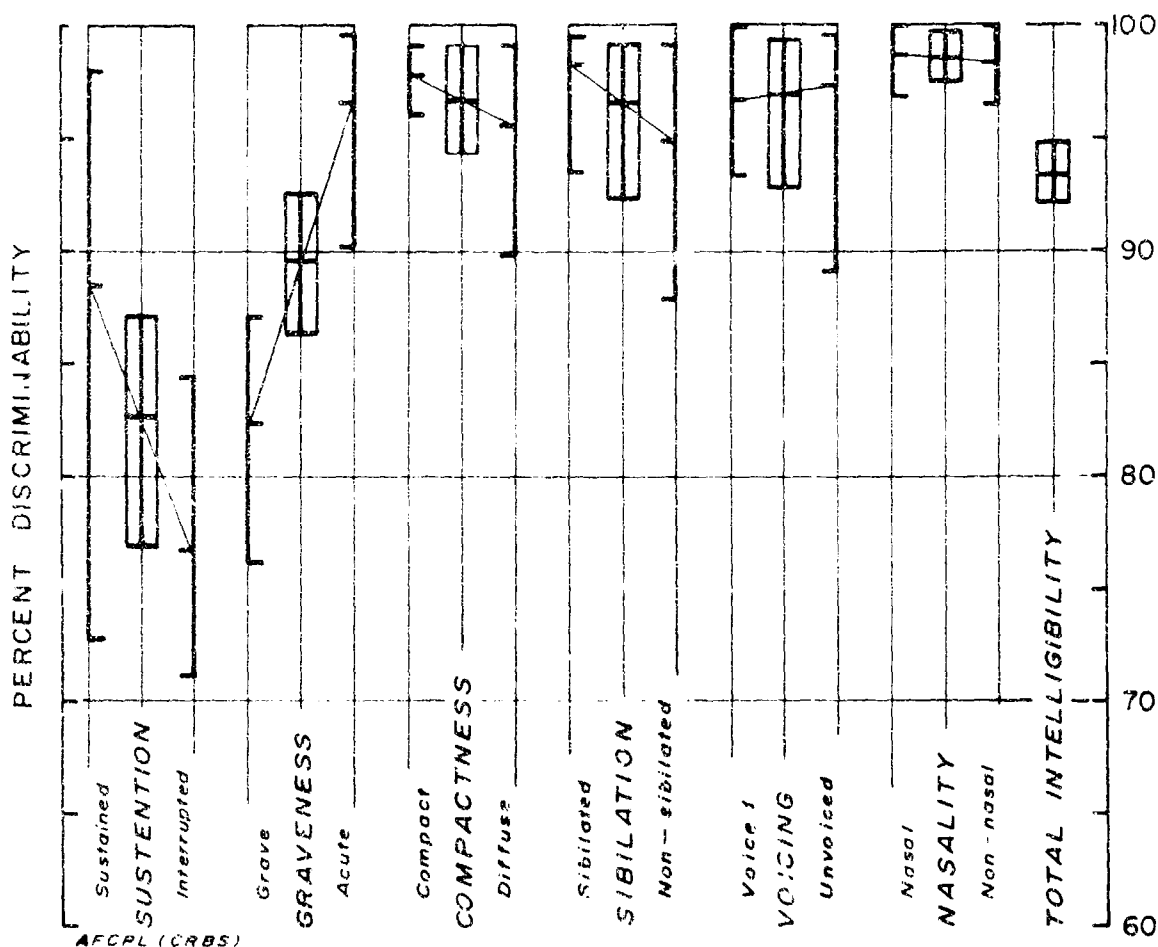


Figure 1. "State-of-the-art" of 2400 bit-per-second channel vocoders. The bars present the average, best, and poorest performance obtained in a survey of current channel vocoder systems, for the six fundamental components of intelligibility measured with the Diagnostic Rhyme Test (DRT), as well as total intelligibility scores.

the major deficiencies of present vocoder technology, and also by establishing a reference against which new systems and processing techniques can be compared and evaluated.

The DRT was also used in a series of experiments, conducted by C. P. Smith at AFCRL, to determine the performance characteristics of a processing method (voice-pattern matching) for speech compression developed at AFCRL. A battery of tests was performed using various combinations of stored voice patterns. Listening crews determined the total

intelligibility, and the intelligibility for the six fundamental components of the DRT, as functions of several parameters, such as the number of patterns utilized and the spectrum data rate. The data are summarized in Figure 2, which compares the intelligibility obtained with this technique with that of a channel vocoder using conventional pulse-code modulation. The results showed that pattern-matching can provide a significant reduction in the data rate of a vocoder system while providing a relatively small reduction in the speech intelligibility.

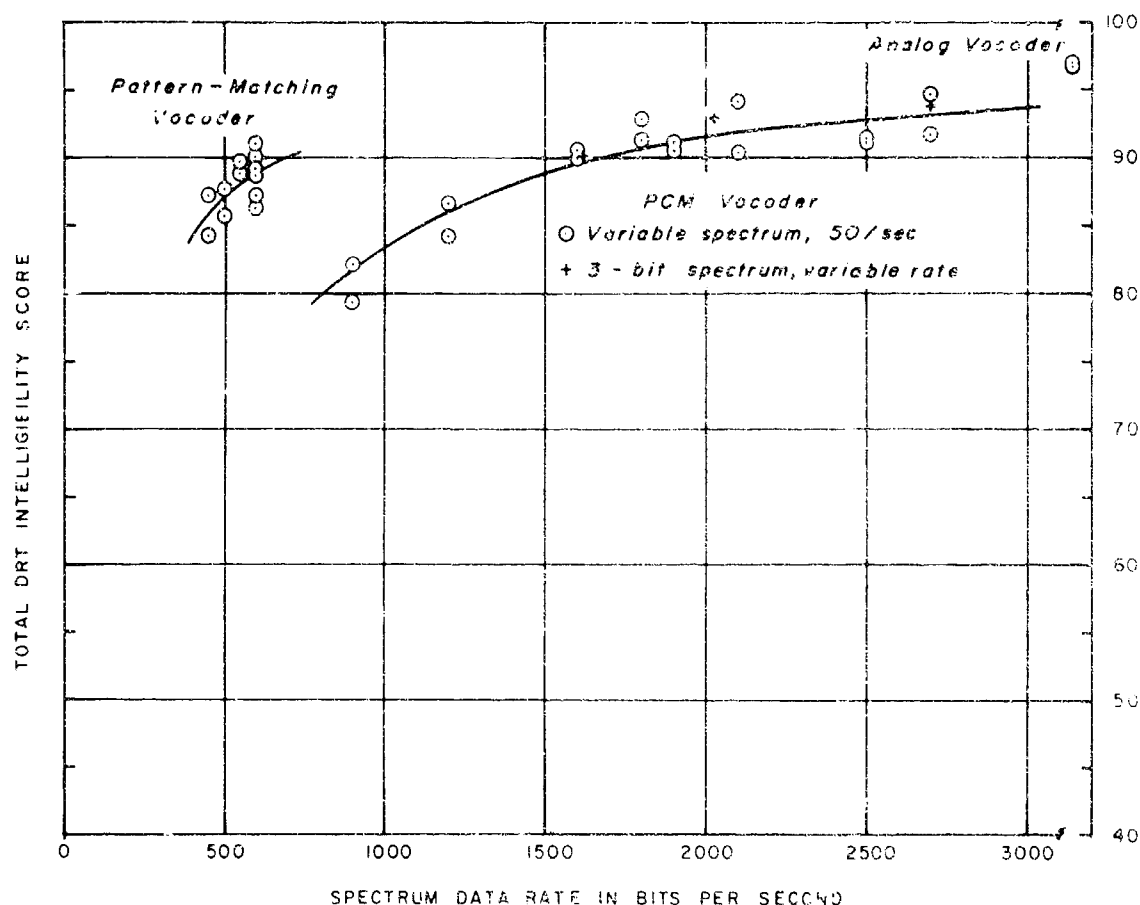


Figure 2. Intelligibility of pattern-matching vocoder compared with conventional vocoder. Each point* represents the intelligibility score of one or more tests, obtained with a crew of eight listeners, in which the processing mode was evaluated.

MULTISENSOR DATA CONSOLIDATION AND INTERPRETATION

The inability of any given sensor to provide unambiguous information on targets of military interest, in the presence of both natural and man-made interference, has led to the proliferation of space-borne, air-borne, and ground-emplaced sensor systems. This, in turn, has led to increasingly serious problems of communication-bandwidth conservation and semiautomated data interpretation.

Research in multisensor data consolidation, at AFRL's Data Sciences Laboratory, is mainly focused on the question, "What is there that is common

to all sensor measurement processes?" An answer to this question could lead to very significant savings in the development of unified data-compaction procedures, with devices operating close to the data sources in contrast to many radically different devices operating well downstream from the sources.

In order to evaluate the relative merits of various measurement data-consolidation theories and procedures, prior to their implementation in costly hardware, an extensive signal data-manipulation capability has been evolved by the Laboratory's Dynamic

Processes Branch under the guidance of Charlton M. Walter. This capability is based on the Data Sciences Laboratory's Experimental Dynamic Processor (the DX-1 System), a dedicated, memory-sharing, polymorphic digital processor with extensive sensor-data inputting, special microprocessing, and on-line color-display-generation features.

The approach taken has represented the first computer-oriented graphic realization of an important mathematical technique based on the representation of each complex signal as a single point in an N-dimensional vector space. The behavior, in time, of large ensembles of signals can then be considered as families of "trajectories" in this multidimensional space. From these views the investigator can begin to develop a feel for the statistical and dynamical structures of given ensembles of signals—for example, signatures of aircraft, or of missiles as seen by particular radar systems. He can also begin to answer such important questions as the extent to which signatures belonging to different sources can be distinguished one from the other. The data can be observed from many different points of view in order to determine the sensitivity of different data-consolidation and signature-categorization procedures, utilizing the processor-controlled color display of the DX-1 System. The display shows just what any given

classification or compression scheme is doing to the raw signature data in terms of appropriate transformations on the signature vectors in the N-dimensional vector space.

Specific applications of the data-consolidation theory have been made in the areas of speech-bandwidth compression/resynthesis and in the problem of multisensor acoustic-signature consolidation and categorization. In speech-bandwidth compression, a collaborative effort with C. P. Smith of the Digital Speech Branch, Data Sciences Laboratory, has shown that an additional factor of 3-to-1-compression can be achieved, over present channel vocoder systems, with essentially no loss in intelligibility. In the consolidation and classification of acoustic-signature data from a limited number of sources, a bandwidth compression of approximately 100 to 1 can be achieved with no degradation in the classification accuracy, using the same technique.

The Experimental Dynamic Processor has also been used to analyze the performance of a type of air-to-air radar target-signature categorization system. Preliminary results indicate categorization efficiencies in the 80% to 95% range are feasible, but not the 99+% figures originally quoted by the system designers.

A NOVEL TYPE OF ENDFIRE ANTENNA WITH INCREASED GAIN AND IMPROVED PATTERN PERFORMANCE

Significant progress in the field of endfire antennas has been achieved in the Microwave Physics Laboratory of AFCL.

The gain of conventional optimized endfire antennas (for example Yagis, helical, disk, or dielectric antennas), is approximately proportional to their structural length, up to about 15 dB gain. For higher gains (in the 20-dB range), however, such antennas become impractically long and cannot be tolerated for many applications because their gain does not increase proportionally with length above about 15dB. The explanation for this unfavorable behavior is straightforward: the usual dipole feed does not give sufficient excitation efficiency for surface-wave propagation on longer antenna structures.

Investigations performed by Dr. Hermann W. Ehrenspeek of the Microwave Physics Laboratory have shown that the gain limitations of such conventional endfire antennas can be overcome by replacing their feed system—in many cases a combination of a feed dipole and a reflector—by a short backfire as a

highly efficient surface-wave launcher for the endfire structure. As a result, a cavity-fed endfire antenna is obtained whose gain now increases proportionally with its structural length. The concept of the short backfire has been described in several OAR publications, for example, in the *Proceedings of the C & R Research Applications Conference, Vol. 1*, 12 March 1967.

Figure 1 shows a sketch of the new antenna type, and Figure 2 shows its gain curve as a function structure length. It should be noted that a conventional endfire would require a length of approximately 25 wavelengths for a gain of 20 dB (isotropic) compared to only 10 wavelengths for the cavity-fed endfire.

Fortunately, the gain increase is combined with an essential improvement in pattern performance. A sidelobe level lower than -20 dB in E and H plane, and a backlobe level lower than -30 dB, are readily achievable.

The new type of endfire antenna should prove to

be advantageous for many types of communication, telemetry, and tracking systems. Also, because of the shortened length of the antenna, it could widely extend the use of endfire antennas in space technol-

ogy. Several applications of the short backfire antenna have already been made in operational-system design.

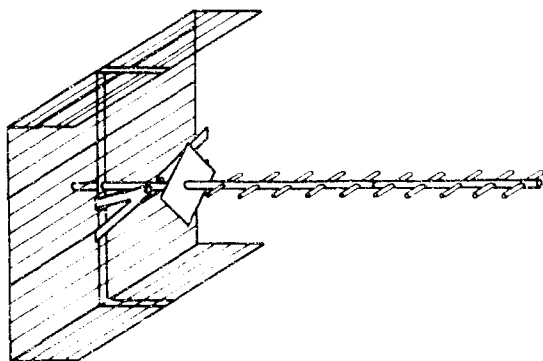


Figure 1. Cavity endfire antenna.

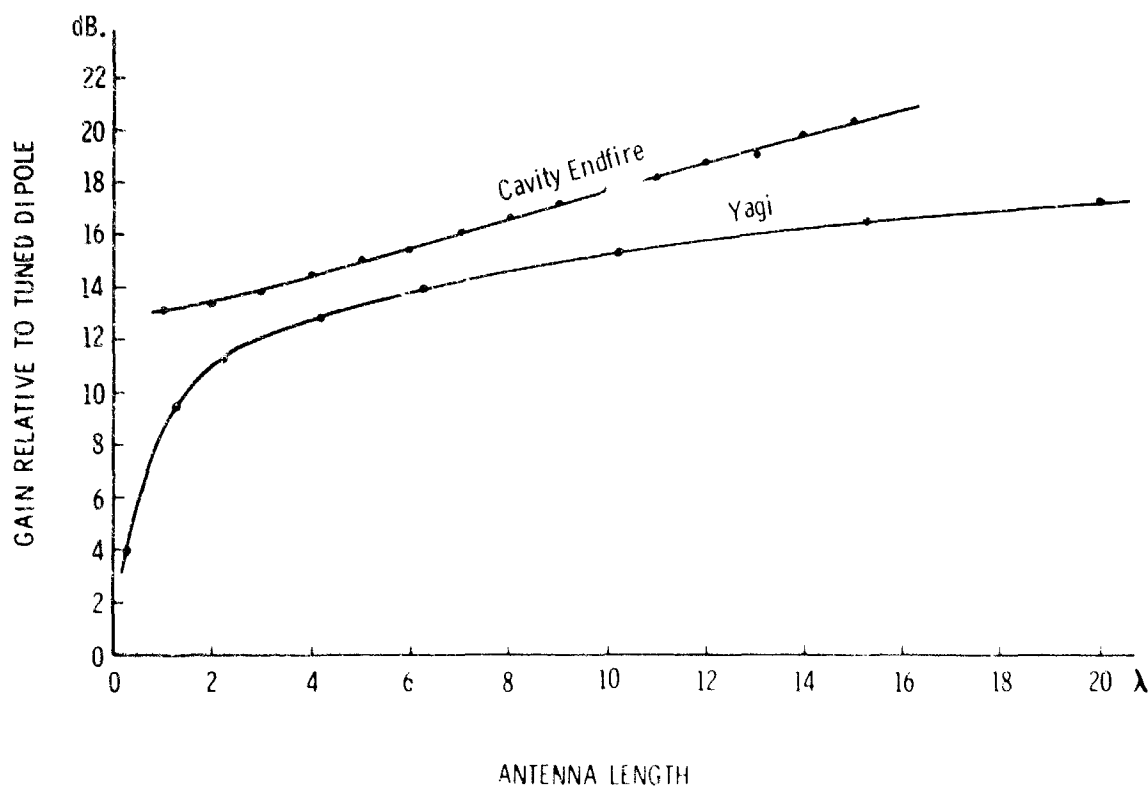


Figure 2. Gain curve of cavity endfire antenna as a function of structure length.

satellites, balloons, and sounding rockets—sabar

RECORD-SIZE BALLOON SENT TO RECORD ALTITUDE

The Aerospace Instrumentation Laboratory of AFRL launched a 28.7-million-cubic-foot (810,000 m³) research balloon in September 1968 which reached an altitude of 160,000 ft (49 km). Two records were established: the balloon was the largest ever launched, and the altitude was the highest ever attained by a research balloon.

This balloon was designed by AFRL for the

Army Electronics Command. It carried instruments for measuring atmospheric composition, pressure, temperature, density, ozone, and wind motion near the stratosphere, plus 285 pounds (129 kg) of ballast; the total load was 425 pounds (193 kg). The huge gas envelope was fabricated from unreinforced polyethylene only 0.45 mils (1.14×10^{-3} cm) thick. This very-thin material required extreme care in handling



Figure 1. The 28.7-million-cubic-foot balloon just before launch. The major portion of the balloon's 587-foot length is still encased in the launch sleeve.

by the launch crew during layout, inflation and launch.

AFCRL launched this polyethylene balloon from the White Sands Missile Range, with Arthur O. Korn, Jr. of AFCRL as the Flight Test Director for the launch. A new technique for launching was also successfully tested on this large balloon. The uninflated portion of the system was incased in a polyethylene sleeve. (See Figure 1) When the balloon was launched, the sleeve prevented the undeployed portion from "sailing" in the wind. As the balloon ascended, the sleeve opened as planned. At the time of launch, the length was 587 feet (179 m). At ceiling, because of the expansion of the helium caused by the decreased atmospheric pressure the balloon assumed an onion-shaped configuration of about 352 by 410 feet (107 by 125 m). It traveled in a westerly direction at about 10 miles per hour (4.5 m/s). The flight was terminated near Needles, California, after 18 hours.

The flight represents a significant advance in balloon development. Polyethylene is the basic material used to construct research balloons, the conventional capacity of which is about 5 million cubic feet ($140,000 \text{ m}^3$). The previous record size for polyethylene balloons (but not for balloons fabricated from other materials) was 13.5 million cubic feet ($378,000 \text{ m}^3$); that balloon was launched by AFCRL in 1965. Five fiber-reinforced Mylar balloons having a volume of 26 million cubic feet ($730,000 \text{ m}^3$), flown by AFCRL for NASA in 1966 and 1967, were the previous record size.

On 23 September 1969, another balloon with a capacity of 30.3 million cubic feet was flown for the Army Atmospheric Sciences Laboratory. It had a total load of 425 pounds (193 kg).

Another similar flight was planned for NASA for 6 November 1969. The balloon was to have a capacity of 34 million cubic feet, and was to carry over 14,000 pounds, the largest payload ever carried.

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FY 69

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This portion of the publication provides information on documented material which originated in relation to the research efforts. The individuals named as contacts were chosen as a matter of convenience to facilitate the availability of information.

DEFENSE RESEARCH SCIENCES PROGRAM ELEMENT 61102F

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NUCLEAR PHYSICS

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Photosynthetic Energy Conversion (Project No. 8659)

Contact: Dr. E. Fujimori, Space Physics Laboratory, AFCLL. Tel. Ext. 3211.

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Contact: Dr. B. T. Wolfson, Directorate of Engineering Sciences, AFOSR. Tel. Ext. 45565.

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Contact: Lt Col Richard W. Haffner, Directorate of Engineering Sciences, AFOSR. Tel. Ext. 45565.

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Contact: Dr. D. G. Samaras, Directorate of Engineering Sciences, AFOSR. Tel. Ext. 45565.

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TERRESTRIAL SCIENCES

Stability of Azimuth Control (Project No. 8623)

Contact: G. H. Cabaniss, Terrestrial Sciences Laboratory, AFCRL. Tel. Ext. 3646

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Measurement of the Absolute Acceleration of Gravity (Project No. 8607)

Contact: Bela Szabo, Terrestrial Sciences Laboratory, AFCRL. Tel. Ext. 4285.

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Contact: Ronald M. Straka, Ionospheric Physics Laboratory, AFCRL. Tel. Ext. 2941.

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BIOLOGICAL AND MEDICAL SCIENCES

Rapid Detection and Identification of Pathogens (Project No. 9777)

Contact: Dr. R. V. Brown, Directorate of Life Sciences, AFOSR. Tel. Ext. 45042.

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Lymphatic Absorption of Drugs (Project No. 9777)

Contact: Dr. R. V. Brown, Directorate of Life Sciences, AFOSR. Tel. Ext. 45042.

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BEHAVIORAL AND SOCIAL SCIENCES

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Cross-Cultural Interaction in a Laboratory Setting (Project No. 9779)

Contact: Dr. H. J. Sander, Directorate of Life Sciences, AFOSR, Tel. Ext. 45045.

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ENVIRONMENT

PROGRAM ELEMENT 62101F

Self-Contained Automatic Transmitter (SCAT) (Project No. 4603)

Contact: Dr. F. A. Lewis, Ionospheric Physics Laboratory, AFCRL, Tel. Ext. 4237.

Measuring Total Electron Content in the Ionosphere with the New AFCRL Polarimeter (Project No. 4643)

Contact: A. Klobuchar, Ionospheric Physics Laboratory, AFCRL, Tel. Ext. 2939.

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Tactical Weather Equipment (Project No. 6670)

Contact: B. D. Weiss, Aerospace Instrumentation Laboratory, AFCRL, Tel. Ext. 3174.

Plan Shear Indicator for Real-Time Doppler Radar Identification of Hazardous Storm Winds (Project No. 6672)

Contact: R. J. Donaldson, Jr., Meteorology Laboratory, AFCRL, Tel. Ext. 4407.

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Atmospheric Density Accelerometer and Low-Altitude Density Satellites O1-15 and O1-16 (Project No. 6690)

Contact: F. A. Marcos, Aeronomy Laboratory, AFCRL, Tel. Ext. 3891.

Atmospheric Contrast Attenuation-ISHED LIGHT (Project No. 7621)

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Airborne Thermal Infrared Signal Processing (Project No. 7628)

Contact: Dr. R. S. Williams, Jr., Terrestrial Sciences Laboratory, AFCRL, Tel. Ext. 3670.

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Elastodynamic Near-Field of a Propagating Fault (Project No. 7639)

Contact: Dr. K. C. Thomson, Terrestrial Sciences Laboratory, AFCRL. Tel. Ext. 2495.

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Polar-Cap Absorption Studies (Project No. 7663)

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Atmospheric Motions Deduced from Smoke Trails (Project No. 8624)

Contact: R. W. Lenhard, Aerospace Instrumentation Laboratory, AFCRL. Tel. Ext. 3168.

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Solar-Flare Forecasting from Millimeter-Wave Observations (Project No. 8682)

Contact: P. M. Kalaghan, Microwave Physics Laboratory, AFCRL. Tel. (617) 893-5353.

The Atmosphere of the Planet Venus (Project No. 8682)

Contact: P. M. Kalaghan, Microwave Physics Laboratory, AFCRL. Tel. (617) 893-5353.

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AEROSPACE AVIONICS

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Degradation of Ruby-Laser Output (Project No. 4645)

Contact: Dr. C. Martin Stickley, Optical Physics Laboratory, AFCRL. Tel. Ext. 2694.

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Research in Speech Processing (Project No. 4610)

Contact: C. P. Smith, Data Sciences Laboratory, AFCRL. Tel. Ext. 3712.

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Contact: C. M. Walter, Data Sciences Laboratory, AFCRL. Tel. Ext. 4329.

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A Novel Type of Endfire Antenna with Increased Gain and Improved Pattern Performance (Project No. 4600)

Contact: Dr. H. W. Ehrenspeck, Microwave Physics Laboratory, AFCRL, Tel. Ext. 3723.

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SATELLITES, BALLOONS, AND SOUNDING ROCKETS—SABAR

PROGRAM ELEMENT 63404F

Record-Size Balloon Sent to Record Altitude (Project SABAR)

Contact: A. O. Korn, Jr., Aerospace Instrumentation Laboratory, AFCRL, Tel. Ext. 3474.

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13. ABSTRACT This report summarizes the progress of the Office of Aerospace Research (OAR) for Fiscal Year 1969 in the conduct and support of research for the United States Air Force. The report covers the various aspects of management, including finances, manpower, logistics, research information activities, and planning, and highlights some OAR achievements in the Defense Research Sciences, Exploratory Development, and Advanced Development. A bibliography is included to aid readers in obtaining detailed information on the research programs described.		

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